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DESIGN OF A FILTER-SEPARATOR TEST FACILITY FOR RESEARCH ON FUELS AND EQUIPMENT

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Technical Report AFAPL-TR-68-69

June 1968

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FOREWORD

This report was prepared by Southwest Research Institute, San Antonio, Texas, under Contract F33615-68-C-1216. The contract was initiated under Project Nos. 8174 and 3048, Task Nos. 817411 and 304805. The work was performed by contractor's personnel using Air Force facilities at Wright-Patterson AFB. The design and experimental work reported herein were performed under an earlier contract, AF 33(615)-2327. The program was administered by the Ground Support Branch and the Fuels, Lubrication, and Hazards Branch, Support Technology Division, Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio. The project engineers during the period reported included Mr. Charles R. Martel (APFG), Mr. Paul C. Linder (APFL), and Mr. John L. Morris (APFL).

This report covers design, construction, and operations under one phase of the previous contract between 1 January 1966 and 1 May 1967. This report was submitted by the authors on 10 May 1968. Contractor's identifying numbers are Project No. 09-2277 and Report No. RS-519.

This technical report has been reviewed and is approved.

Robert D. Sherrill

Robert D. Sherrill, Chief
Ground Support Branch
Support Technology Division
Air Force Aero Propulsion Laboratory

ABSTRACT

A 15- to 60-gpm filter-separator test loop has been designed and built for research and development work on jet fuels, additives, and fuel handling equipment. Maximum flexibility has been provided in the loop and in the subsystems for blending and injecting additives, solid contaminants, and water. No materials that are harmful to the newer types of high-quality hydrocarbon fuels have been used in the fuel-wetted components of the loop, and the system consists primarily of aluminum and stainless steel. Initial operations with this loop have been directed toward development of valid single-element test procedures for rating fuel corrosion inhibitors and other additives. The results of the first thirteen tests in this facility have demonstrated its favorable operating characteristics. In these tests, fuel corrosion inhibitors affected principally the plugging rate of filter-separator elements. Considerable scatter was observed in the plugging rates, attributed tentatively to element-to-element variations.

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LIST OF ABBREVIATIONS

AC	Standard air-cleaner test dust ("Arizona road dust"); here refers to standard coarse grade.
AFB	Air Force Base.
AIA	Anti-icing additive, same as FSII (which see); AIA is older, unofficial terminology.
AEL	Free water detector apparatus and method developed by the Aeronautical Engine Laboratory (Navy); covered by MIL-D-81227(WP) and related specifications.
API	American Petroleum Institute; here refers to gravity of petroleum products on an arbitrary scale.
ASA	American Standards Association; here refers to standardized hardware such as flanges, threads, etc.
ASTM	American Society for Testing and Materials; here refers to test method or apparatus under the jurisdiction of this organization.
CRC	Coordinating Research Council; here refers to test method or apparatus developed under the jurisdiction of this organization.
EP	Explosion-proof (electrical equipment). End point (in distillation).
FPT	Female pipe thread, tapered.
F/S	Filter-separator.
FSII	Fuel system icing inhibitor, MIL-I-27686D, consisting of 99.6% 2-methoxyethanol (monomethyl ether of ethylene glycol) and 0.4% glycerin.
FTMS	Federal Test Method Standard.
IBP	Initial boiling point (in distillation).
I.D.	Inside diameter.
IFT	Interfacial tension in liquid-liquid systems, expressed in dyn/cm; here refers to values measured by ring method in accordance with ASTM D 971-50.

LIST OF ABBREVIATIONS (Cont'd)

IPS	Iron pipe size (standard pipe thread).
JP-4	Military jet fuel, MIL-T-5624G, wide-cut type.
JP-5	Military jet fuel, MIL-T-5624G, kerosine type.
lb/Mbbl*	Pounds (of additive) per 1000 barrels (42,000 gallons) of fuel. One lb/Mbbl is equivalent to 0.0238 lb/1000 gal, 10.80 mg/gal, or 2.85 mg/liter. For J-4 fuel, 1 lb/Mbbl is equivalent to 3.77 ppm by weight.
MPT	Male pipe thread, tapered.
NPT	National pipe thread, tapered.
O.D.	Outside diameter
PTFE	Poly(tetrafluoroethylene); correct chemical name for polymers represented by Teflon.
RIO	Red iron oxide; here refers to standard Fisher I-116 material used as test contaminant for filter-separators.
SFV	Superficial flow velocity; here refers to flow through a screen and is defined as volumetric flow rate divided by total area of screen.
SS	Stainless Steel
ST	Surface tension of liquid, expressed in dyn/cm; here refers to surface tension against air, measured by same ring method used for IFT.
SwRI	Southwest Research Institute
TFE	Same as PTFE (which see).
WSIM	Water Separometer Index, Modified, a fuel demulsibility index characterizing the ease of coalescing and settling out dispersed water; determined in accordance with ASTM D 2550-66T. Fuel WSIM values range from 100 (extremely good) to 20 or lower (extremely poor); current minimum specifications for military jet fuels are 70 WSIM for inhibited fuels and 85 WSIM for uninhibited fuels.

*Also written as lb/1000 bbl, and sometimes shortened to "lb" in certain usage in this report.

LIST OF GOVERNMENT SPECIFICATIONS AND STANDARDS*

Federal Standard

FED-STD-791a(3)	Lubricants, Liquid Fuels, and Related Methods of Testing	1 Jul 65

Federal Specifications

VV-K-220a(1)	Kerosene, Deodorized	29 Apr 63

Military Specifications

MIL-T-5624G(1)	Turbine Fuel, Aviation, Grades JP-4 and JP-5	21 Nov 66
MIL-F-8901A(1)	Filter/Separator, Aviation and Motor Fuel, Ground and Shipboard Use, Performance Requirements and Test Procedures for	4 Oct 63
MIL-I-25017B	Inhibitor, Corrosion, Fuel Soluble	22 Oct 62
MIL-I-27686D(1)	Inhibitor, Fuel System Icing	6 Sep 66
MIL-F-52308B	Filter Element, Fluid Pressure	6 Dec 66
MIL-D-81227(WP)(1)	Viewer Kit, Free Water Detector	17 Feb 66

*This list inclues specifications and standards referenced in this report. Issues and dates are the latest available at the time of writing this report.

SECTION I

INTRODUCTION

Filter-separator equipment is used almost universally in military and commercial operations involving jet fuel handling, in order to remove water and solid contaminants and to deliver clean fuel to aircraft. Almost all such equipment is designed with replaceable filter-coalescer elements and either permanent or replaceable "stripper" or "separator" units that act as hydrophobic barriers to prevent the passage of suspended drops of water. In such equipment, the primary or "first-stage" filter-coalescer elements perform the dual function of removing solid contaminants and coalescing any finely dispersed water droplets into larger drops. These drops settle to the bottom of the unit and are drained manually or automatically. Entrainment of any smaller, poorly coalesced drops in the fuel stream is minimized by the hydrophobic barrier of the separator stage.

Military filter-separator design has been standardized with respect to the filter-coalescer elements. Specification MIL-F-52308B, Filter Element, Fluid Pressure, gives the basic dimensional and material requirements for military standard elements. The performance requirements and test procedures for such elements, and for complete filter-separators, are given in Specification MIL-F-8901A, Filter-Separators, Aviation and Motor Fuel, Ground and Shipboard Use, Performance Requirements and Test Procedures for. Practically all new-design filter-separators for military use are built to accept elements of this type. The hydrophobic-barrier separator stage and the filter-separator vessel itself cannot be placed on such a single-standard basis, since the wide variety of end-use requirements will dictate different types of equipment. In general, modern designs for military filter-separators made use of a permanent separator stage consisting of a PTFE (polytetrafluroethylene) coated screen canister or basket.

When military-standard elements are tested for qualification or acceptance, the procedures and requirements are governed for the most part by MIL-F-8901A. This specification includes certain simple tests on the elements themselves and an extensive series of performance tests on elements installed in a housing. Military-standard elements are often tested in a two-element housing. This applies only to centralized procurements of such elements. The individual military services have different practices in their procurement of various elements for specific equipment, and such elements are often tested in the vessel actually used in service.

In MIL-F-8901A, test equipment and procedures are spelled out in some detail, but there is still room for very wide variations among the practices at various individual test facilities. There is no "standard" test equipment that can be used as a baseline in comparing different elements, or

in studying the effects of different fuels, additives, and contaminants on filter-separator performance. Poor reproducibility of results among different organizations has been a recognized fact in filter-separator testing, and poor repeatability within the same facility is often the rule rather than the exception.

Most test work involving filter-separators consists of performance testing for purposes of development, qualification, or acceptance. For such uses, the general lack of test precision is undesirable but up to now has been considered unavoidable. When filter-separator tests are used to evaluate fuels or additives, the definition of test equipment and procedures, and the improvement of test precision become extremely important. As a case in point, one may consider the possible use of a filter-separator test in qualifying fuel additives. Such a test could be of much more significance than (for example) a bench test such as the ASTM-CRC water separometer. However, the imposition of such a test requirement would presuppose the existence of reasonably well standardized equipment and procedures.

Another need for improvement in filter-separator testing is evident in the area of more basic investigations. A considerable amount of small-scale work has been and is being performed to elucidate the complex interrelationships among fuel and contaminant properties, operating variables, filter media, and performance. Enough progress has been made in these areas that confirmatory work in larger equipment is needed. For such work, a filter-separator test facility must have maximum flexibility and precise control over all operating variables.

Finally, there is a need for an experimental fuel handling facility designed specifically for the newer hydrocarbon fuels. Such design is primarily a matter of selecting materials of construction in conformance with known principles. If the facility incorporates only these materials known to be harmless to such fuels, then it can be used to check the effects of other, unknown materials.

All of the factors discussed in this general background have entered into the reasons for designing and building the test facility described in this report. Early experience in using an existing test facility in studying fuels and additives had indicated a number of shortcomings and had pointed out the need for a self-contained facility designed and engineered for such work.

This report describes the design, construction, and early operating experience with this new test facility. It consists of a pumping system with flow capability of 15 to 60 gpm, plus auxiliary equipment for fuel-additive blending and for contaminant preparation and injection. The facility is designed primarily for testing single filter-separator elements, but multiple-element units can be tested up to the 60-gpm limit. The primary metals used for fuel-wetted parts are aluminum alloys and stainless steel. Copper

alloys and carbon steels are excluded. For purposes of identification in this report and elsewhere, this test facility is termed the "Al/SS loop."

General information on design criteria, layout, equipment, procedures, and initial operating results is given in the following text. More detailed information is presented in appendixes. Further results obtained with this facility will be the subject of future reports.

SECTION II

EQUIPMENT

1. DESIGN BASIS

a. Objectives

The test loop described herein was designed for use in a broad study program on fuel handling. Immediate and potential uses for this equipment include the development of filter-separator test techniques, study of different types of elements and media, study of the effects of fuel and additive variables on element performance, development of test methods for fuel additives, investigation of alternate contaminant control and detection devices, study of static electrification hazards and their control, and study of handling techniques for "thermally stable" and other high-quality hydrocarbon fuels.

To these ends, the design was directed toward maximum flexibility with respect to flow rates and the types and amounts of contaminants to be handled, adaptability for evaluating various types of auxiliary equipment, operability with self-contained recirculating fuel supply or outside source of fuel, and compatibility with the newer types of high-quality fuels. The general layout and piping design were chosen to facilitate draining and cleaning, as well as complete dismantling if necessary. Regular-production components were used wherever possible, not only to reduce costs but also to facilitate duplication of the test facility or parts of the facility by any interested organization.

b. General Layout and Design Criteria

Most of the components of this loop are counterparts of those present in any test loop used to evaluate filter-separators. That is, any such loop must have a source of fuel, a fuel pump, systems for injecting and mixing water and solid contaminants, a "test section" consisting of the filter-separator or other device being investigated, a "cleanup" filter-separator or other device to maintain a clean fuel supply, sampling connections, and appropriate controls and instrumentation. Therefore, the general layout of the Al/SS loop is quite similar to that specified in MIL-F-8901A and to that of most filter-separator test facilities. A simplified flow diagram of the Al/SS loop is shown as Figure 1. The only extra feature that is immediately apparent from this diagram is the installation of two Totamitors, one before and one after the test section, as continuous monitors of fuel cleanliness. Unique features of the loop, not apparent from the simplified diagram, will be discussed in subsequent sections of this report.

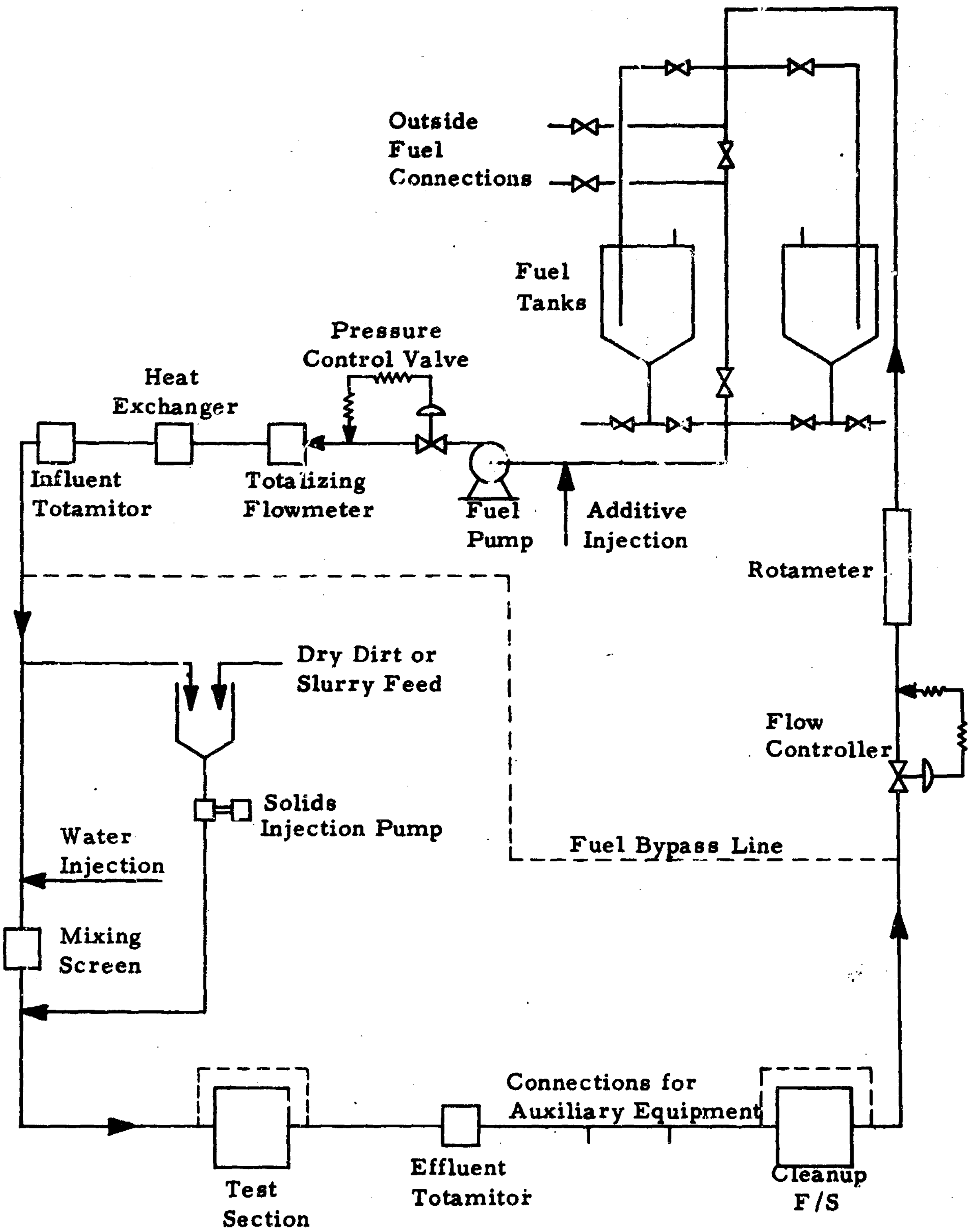

FIGURE 1. SIMPLIFIED FLOW DIAGRAM OF A1/SS LOOP

A general view of the Al/SS loop is shown as Figure 2, and other views are shown in photographs included in Appendix C. It will be noted that components, valves, and piping are installed near the floor or within easy reach, except for the tank-top connections. A clear-floor area is available within the main fuel loop for convenience of operation. All controls, switches, and instruments are on or near the loop, except for emergency switches and the Totamitor indicators and recorders. Pressure and temperature indicating gages for the main fuel loop are panel-mounted in a flow-plan display.

The principal design parameters for this loop are as follows:

Fuel flow rate, 15 to 60 gpm
Fuel pressure, 125 psig maximum (required at pump outlet)
Fuel temperature, 70 to 90°F (control ±2°F with ambient 50 to 100°F)
Water injection rate, 0.01 to 10% of fuel flow rate*
Solids injection rate, 0.3 to 75 mg per liter of fuel
Fuel flow velocity, 6 ft/sec minimum between first contaminant injection point and final sampling or monitoring point

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*10% water at minimum fuel flow rate. 3% water at maximum fuel flow rate.

c. Electrical

All electrical components and wiring are explosion-proof (Class 1, Group D). This permits use of the loop indoors, with adequate ventilation and safety devices, on highly flammable fuels such as JP-4. Total power requirements are 2 kw at 110 V (60-cycle single-phase) and 20 kw at 440 V (60-cycle three-phase).

The loop piping and electrical components are grounded. No attempt was made to bond all flanged joints with "jumpers," since the bolt contacts were assumed to be adequate to equalize the potentials of the various loop components. The only design feature aimed specifically at reducing static electrification hazards was the placement of the discharge end of the tank return line below the normal fuel level in the tanks. No accidents, incidents, or phenomena attributable to fuel electrification have been encountered during operation.

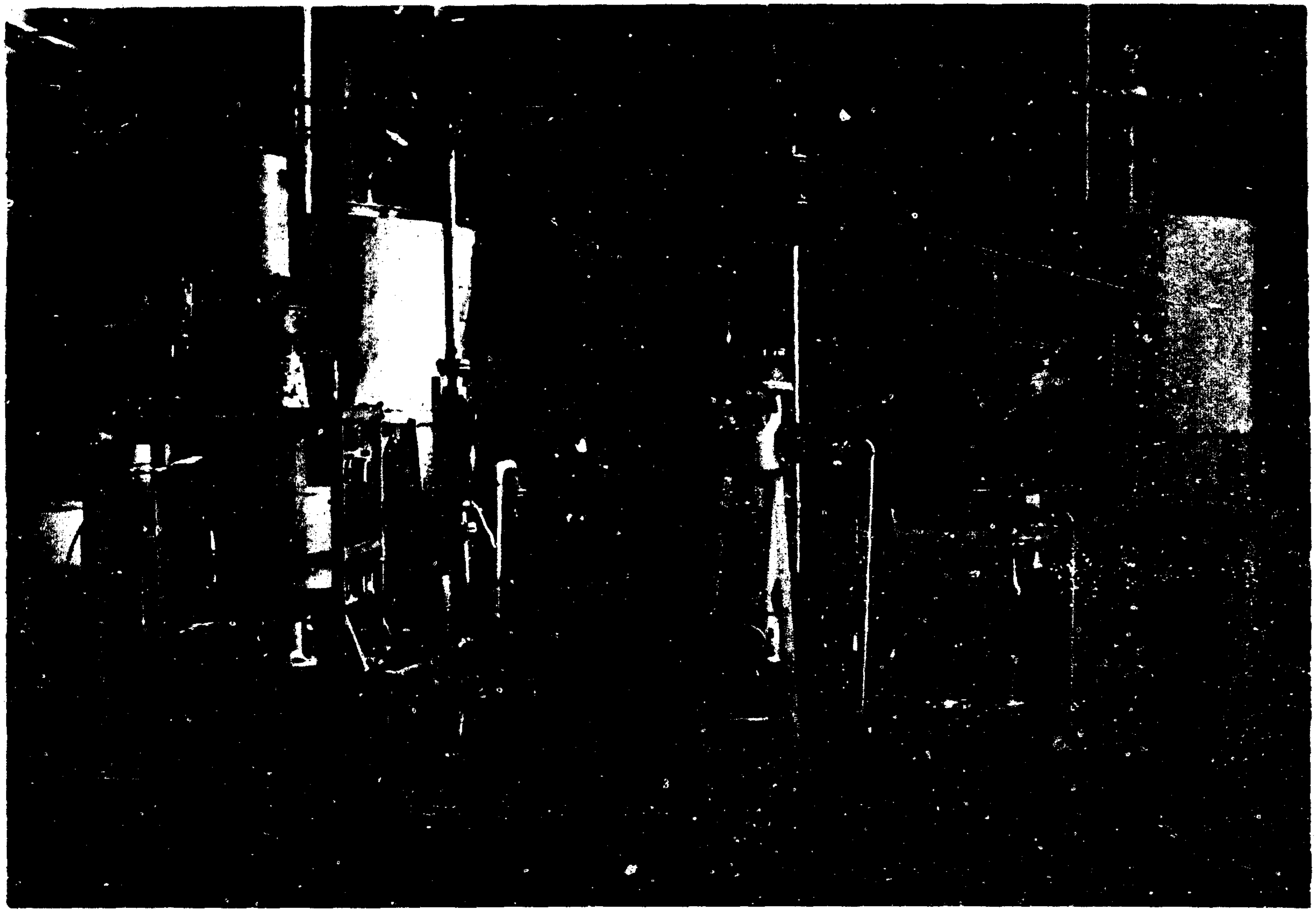


FIGURE 2. GENERAL VIEW OF Al/SS LOOP

d. Materials of Construction

The selection of materials for the fuel-wetted portions of the loop was governed by the following exclusions: No materials known to have adverse effects on high-quality thermally stable fuels would be permitted, and no materials that could contribute contaminants to the system would be permitted. In effect, this eliminated copper-base alloys, Buna N type rubbers, and bare carbon steel or low-alloy steel.

The exclusion of copper-base alloys and Buna N type rubbers is based on general background and on data from a previous program* indicating extremely adverse effects of these materials on the thermal stability of JP-7 fuel. In that program, it was found that 5000 and 6000 series aluminum alloys and an austenitic stainless steel (Type 304) had no significant effect on fuel thermal stability. It was also found that tank coating materials qualified for Air Force use did not have any significant effect. However, such coatings were not used in the Al/SS loop because of the difficulty in cleaning such surfaces, in comparison with cleaning bare metal surfaces.

Based on these considerations, the fuel-wetted metals in the loop were restricted to 5000 and 6000 series aluminum alloys and stainless steels. These restrictions created some rather serious problems in selection of components, since the avoidance of copper and brass eliminated many items that otherwise would have been quite satisfactory. It should be noted that even silver-soldered or brazed joints must be avoided to comply with this restriction. In the whole loop, the only fuel-wetted component for which an exception had to be made was the totalizing flow meter, where a silver-soldered joint was permitted in order to expedite delivery.

The primary nonmetallic materials in the fuel-wetted portions of the loop are fluorinated rubbers (Viton type) and polytetrafluoroethylene (PTFE, Teflon). Also present are minor amounts of polycarbonate plastic, acrylic plastic, glass, and asbestos/graphite. Buna N rubbers were excluded rigidly with one major exception: The stator of the solid-contaminant injection pump is Buna N, since the manufacturer had found it impossible to mold fluorinated rubbers with the necessary close dimensional tolerances.

The choice of materials for the subsystems (additive, solids, and water) will be discussed individually.

*Johnston, R. K. and Monita, C. M. (Southwest Research Institute), "Jet Fuel Stability and Effect of Fuel-System Materials," AF Aero Propulsion Lab. Report AFAPL-TR-68-20, Feb 1968.

2. MAIN FUEL LOOP

a. Flow Plan and Major Components

A simplified flow plan for the main fuel loop was shown as Figure 1, and a more detailed flow plan is given in Appendix C. The piping and valve arrangement permits recirculating from and to either tank, pumping from one tank to the other, or pumping from an outside tank to the same or another outside tank. With any of these arrangements, flow can be directed either through the test loop or through the bypass line. In either case, the flow controller is operative.

Additives are injected into the fuel pump suction line for thorough mixing with the fuel. This injection point can also be used to inject water or any other liquid to be added in relatively small amounts.

The pump discharge pressure is reduced and controlled by means of a regulator that maintains a constant downstream pressure. The balance of the pressure drop occurs in the test section piping, cleanup filter-separator, and finally in the flow controller. The fuel temperature in the line feeding the test section is controlled automatically, using a steam-water heat exchanger. A mixing screen is provided in the fuel line after the water injection point to disperse and mix the water with the fuel. Fuel cleanliness is monitored by means of two Totamitors, one in the influent fuel line (before contaminant injection) and one in the effluent fuel line from the test section.

The sequence of contaminant injection and mixing should be noted here, since it is somewhat different from that specified in MIL-F-8901A. Here, the sequence, in the direction of main fuel flow, is as follows: (a) takeoff of clean fuel to solids injection system, (b) water injection and mixing, and (c) solids injection. With this sequence, premix of the solids in the injection system is accomplished with clean, dry fuel. In the usual MIL-F-8901A system, wet fuel is taken to the solids mixing and injection system.

Not shown in the simplified flow plan are the many low-point drain valves that permit removal of all but traces of fuel from the loop. Most of the fuel is pumped out to scrap tankage via a closed system, and the remainder is drained into a collection trench or into containers.

In the following sections, the fuel-loop components are described in general terms. More detailed design information, drawings, photographs, and a complete list of components are given in Appendixes B, C, and D.

b. Fuel Tanks

Two cone-bottom welded 750-gal aluminum tanks were designed and fabricated by SwRI for this loop. The tanks are made of 5052-H32

aluminum alloy. Each tank has a bottom connection for direct feed to the fuel pump, an overhead return line extending to near the bottom of the tank (to minimize static charge generation), a vent line, a manhole with cover, a gage glass, and an aluminum frame for floor-mounting. The working capacity of each tank is restricted to 600 gal in the present operation, largely because of building safety regulations. A 600-gal load of fuel gives a 10-min fuel supply at the maximum flow rate of 60 gpm; this 10-min supply is the minimum allowable in tests run in accordance with MIL-F-8901A. For tests run at 20 gpm, the flow rate used in most of the program, the tank holds a 30-min fuel supply.

c. Outside Fuel Supply

The outside fuel supply system is not a part of the loop proper. However, the system used in most of the work to date will be described briefly. Uninhibited JP-4 or JP-5 base fuel is stored in two 15,000-gal underground bare-steel tanks. Fuel is drawn from one of these tanks through a 1-1/2-in. aluminum line by means of a positive-displacement pump located within the building and is pumped at approximately 40 gpm through a cleanup filter-separator rated at 60 gpm, and thence into one of the fuel tanks of the Al/SS loop. Any subsequent blending operations are performed within the loop itself. This system has worked well in supplying clean, dry base fuel to the test loop. Naturally, it would be unsatisfactory for work with high-quality thermally stable fuels, where nonferrous or coated storage tanks would be required.

d. Fuel Pump

The selection of the main fuel pump presented a rather difficult problem because of conflicting requirements. On the one hand, the pump would be required to deliver rather low volumes at relatively high pressures (say 15 gpm at 100 to 125 psig); for such service, a positive-displacement pump would be well suited. However, it was also anticipated that the pump would encounter badly contaminated fuel in the event of filter equipment failure; this led to the conclusion that the use of a positive-displacement pump would be inadvisable. The selection of a suitable centrifugal or turbine pump was handicapped by the limitations placed on materials and by the long lead times required by many of the manufacturers. The pump finally selected is a single-stage centrifugal pump with direct 25-hp electric motor drive, rated at 410 to 445 ft head at 15 to 60 gpm. This pump is considerably overdesigned for the intended service, and it is probable that a pump better tailored for the service could have been selected had time permitted. For high-pressure use, the pump is equipped with a 9-5/8-in. impeller; for use at moderate pressures, an 8-in. impeller is installed. Pump performance curves with the two impellers are shown in Figure 3. It will be noted that the pump is operating at low efficiency, in what amounts to a near-shutoff condition, over the entire range of flow rates from 15 to 60 gpm; hence, most of power input goes into heating the fuel rather than into hydraulic power.

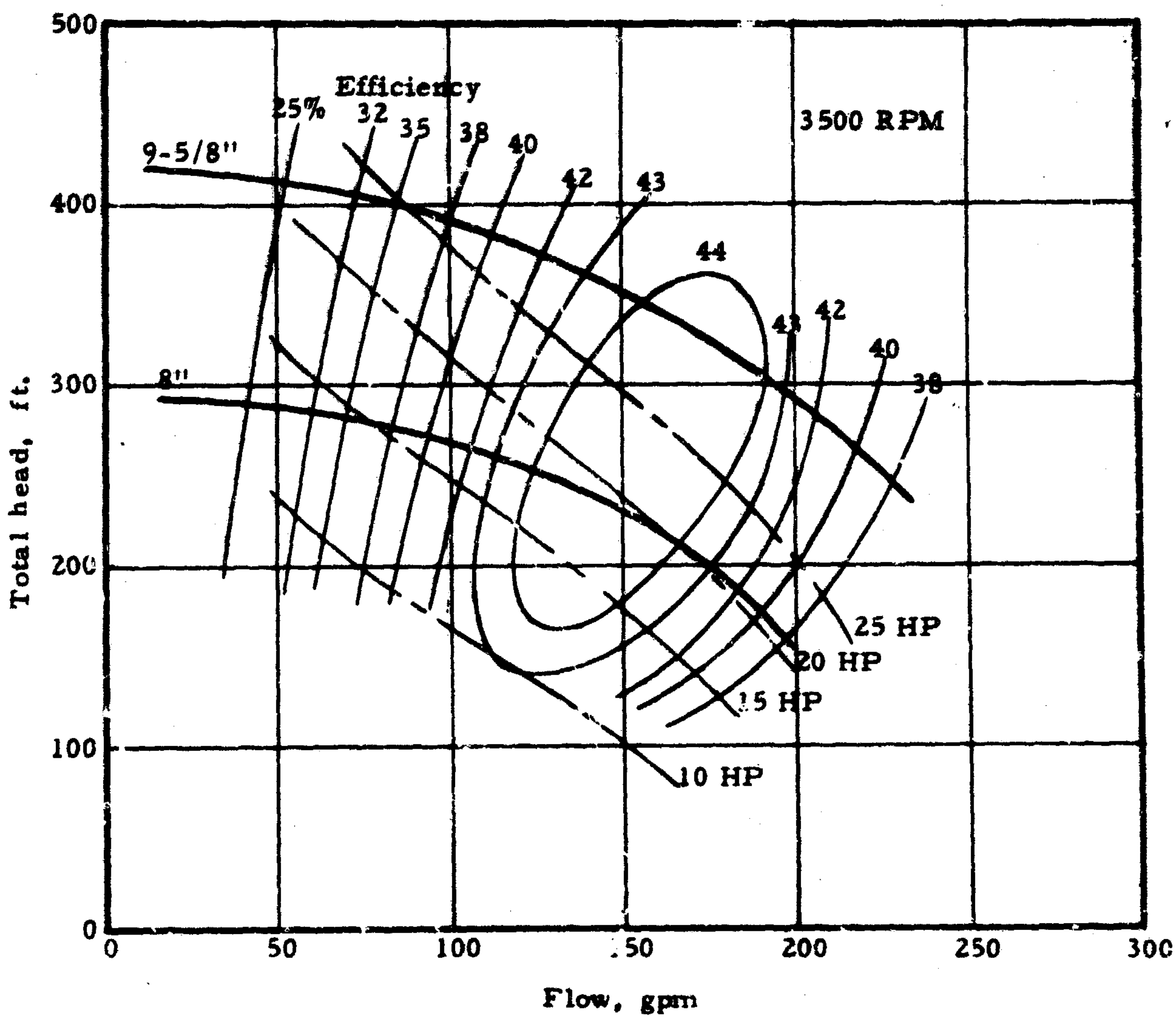


FIGURE 3. CENTRIFUGAL PUMP PERFORMANCE CURVES

The temperature rise across the pump for various conditions was estimated from the pump performance curves, assuming that all input power is converted to heat. This assumption is fairly close to the actual situation when the pump is operating at low efficiency. The following temperature rises were estimated:

	15 gpm	20 gpm	30 gpm	60 gpm
9-5/8-in. impeller	16°F	12°F	8°F	5°F
8-in. impeller	8°F	7°F	5°F	3°F

If anything, these estimates are probably low, based on operating experience with the 8-in. impeller at 20 gpm, where the typical temperature rise across the pump is some 7 to 11°F.

The main fuel pump has been discussed in some detail because the overdesign and the consequent fuel heating have affected the operation of the heat exchanger and the loop temperature control.

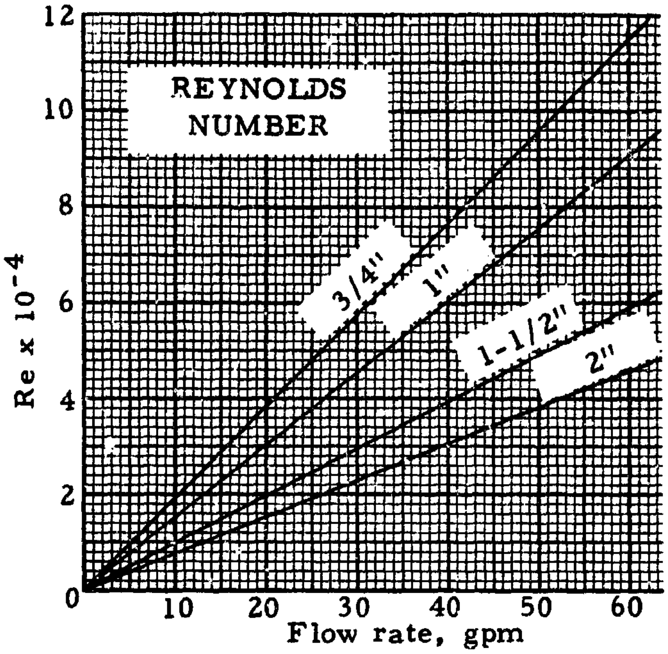
It appears in retrospect that a positive-displacement pump would have been a better choice for this purpose; in normal operations, it is quite improbable that any solid materials will be ingested in sufficient quantities to give immediate damage.

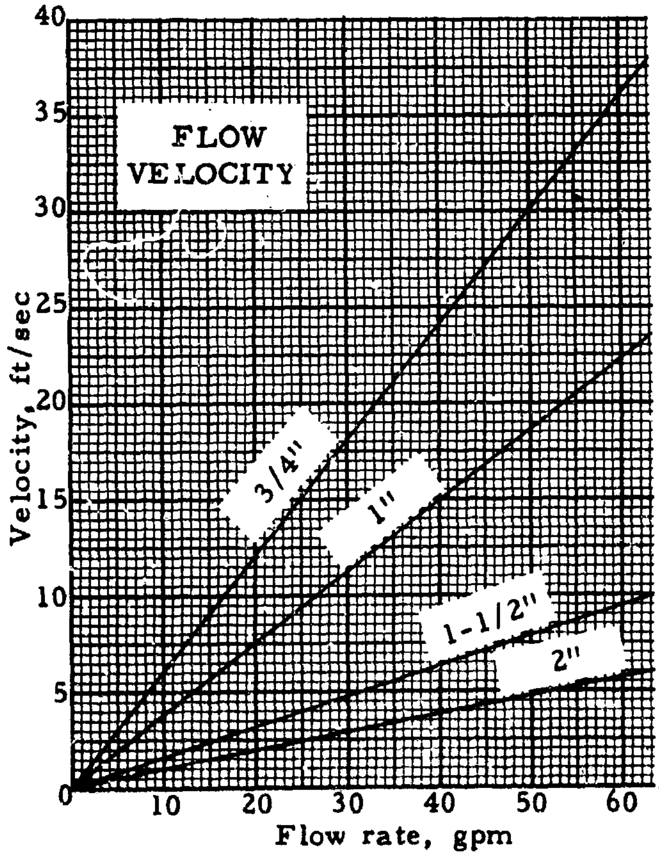
e. Lines, Fittings, and Valves

All fuel lines and fittings are 6061-T6 aluminum alloy. Welding elbows and tees are used wherever feasible, and standard flanged fittings are used where necessary. One set of special couplings (Victaulic type) is used for a mixing-screen assembly that must be removed frequently for cleaning. In the very few instances where threaded joints are required, they are assembled with PTFE tape as a thread lubricant and sealant. The use of flanged and welded fittings as the primary method of assembly was dictated by the need to avoid "pockets" that would trap fuel or contaminants and interfere with efficient flushing of the loop. Another consideration was ease of dismantling all or portions of the loop for special cleaning or modification.

Based on the same general considerations, practically all of the line valves are stainless steel ball valves with PTFE seats and packing. Low-point drain valves and sampling valves are of the same type, mounted in special bosses welded to the main fuel pipe. No special sampling probes are used; each fuel sampling line is connected directly to the side of the fuel flow line.

Aluminum pipe for the main fuel lines was selected from standard Schedule 40 pipe sizes in accordance with the loop design parameters: fuel flow rate, 15 to 60 gpm, and fuel flow velocity at least 6 ft/sec in the critical section between the first contaminant injection point and the final point for effluent quality monitoring or sampling. Minimum pipe sizes were dictated by pressure-drop considerations. Flow characteristics for JP-5 fuel in Schedule 40 pipe are plotted in Figure 4. It can be seen that 3/4-in.





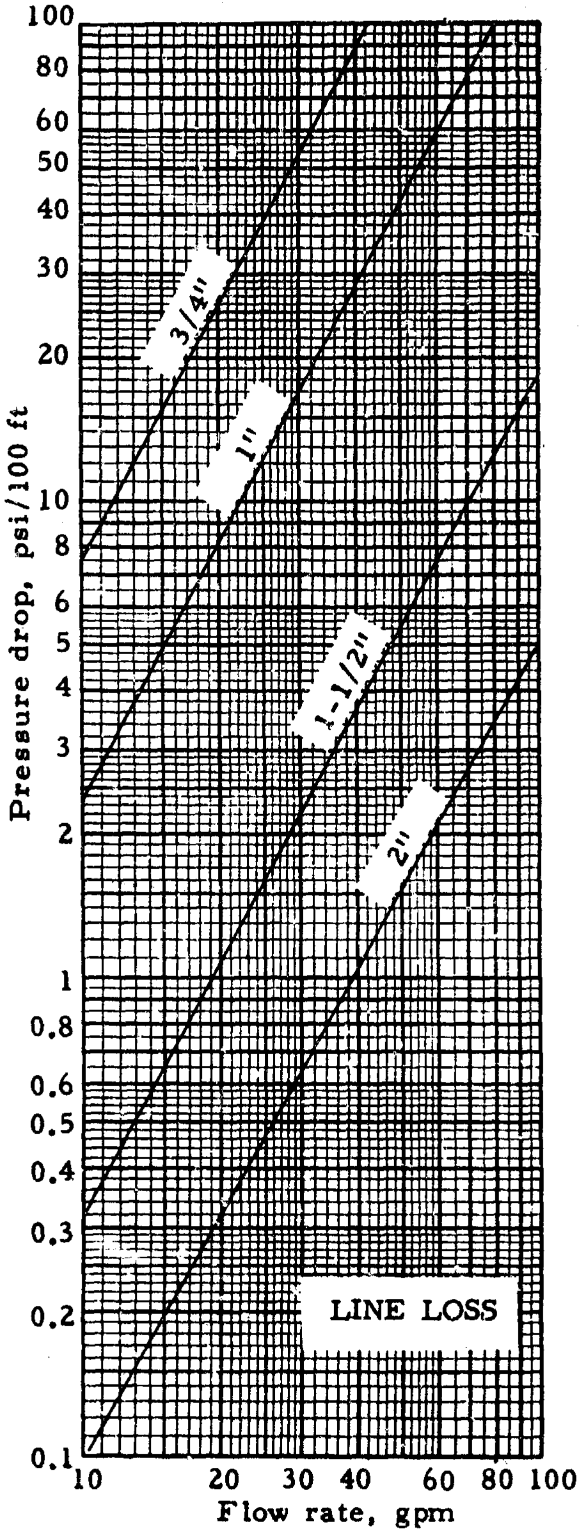


FIGURE 4. PIPE FLOW CHARACTERISTICS

Schedule 40 aluminum pipe
JP-5 fuel (0.82 g/cm^3, 2 cs)

pipe is completely unsuitable because of high line losses, even at moderate flow rates. Estimates of pipe length and equivalent lengths of fittings and components indicated that 1-in. pipe for the critical high-velocity section and 2-in. pipe for the balance of the main fuel lines would be adequate for operation with the available pump head; the loop was designed on this basis. The use of 1-in. pipe gives a fuel flow velocity of 5.6 ft/sec at 15 gpm, i.e. very slightly below the design criterion of 6 ft/sec that is specified in MIL-F-8901A. This compromise was justified on the basis that (a) the figure of 6 ft/sec is believed to be somewhat arbitrary, (b) the Reynolds number in 1-in. pipe with 15 gpm of JP-5 fuel is 23,000, far above the critical regime and well into the turbulent flow regime, and (c) it was anticipated that most test work would be performed at 20 gpm and very little at 15 gpm. In 20-gpm tests, the flow velocity in the 1-in. section is 7.5 ft/sec. Operating experience has indicated that the loop operates satisfactorily over the entire range of design flow rates. Ample pump pressure is available at the maximum flow rate to overcome the frictional resistance of the piping and components, plus plugging of the test element to a 40-psi pressure differential.

f. Pressure and Flow Control and Measurement

Referring to the simplified flow diagram (Figure 1), it will be noted that the flow controller is located downstream of all components except the rotameter. This choice of location was somewhat arbitrary, being dictated mainly by the desire to run the test section under pressure (simulating field conditions) rather than with wide-open flow downstream of the test section. With this downstream location of the flow controller, the fuel supply pressure must be regulated in order to protect equipment. Some of the components, such as the rotameter, cleanup filter-separator, and a special transparent test housing, are not designed to withstand full pump pressure. Without regulation of supply pressure, any temporary shutoff of flow would result in immediate overpressurizing and probable damage to any of these weaker components upstream of the shutoff point. It should also be noted that the flow controller is located downstream of the junction point where the fuel bypass line rejoins the main loop. This location ensures that the flow controller is in line and operative during all flow operations, so that the pump cannot "run away." The pump performance characteristics are such that wide-open operation would overload the motor.

The pressure control valve is a pilot-operated unit, actuated by fuel pressure, of the same type used on fuel handling equipment in the field. The flow controller is the same general type. When originally installed, these units did not operate at all satisfactorily, and changes had to be made to throttle the pressure supply lines and to stablize the operation. Flow control is still not fully satisfactory. During a test, as the test-section flow resistance builds up because of element plugging, the flow controller will not compensate fully but must be reset manually. It is believed that this behavior is inherent in the controller and that no better results can be achieved with this general type of equipment. For better control, a more sophisticated instrument with pneumatic or electrical actuation would be

necessary. Alternatively, for long-term operation in tests at a single constant flow rate, a simple spring-loaded flow-control valve can be fully as satisfactory as the unit presently installed.

The totalizing flowmeter and the rotameter are conventional instruments. The only noteworthy feature is the difficulty experienced in getting the totalizing flowmeter modified to meet the restrictions imposed on materials of construction. Even after rather long delays caused by these modifications, it was still found necessary to permit the use of one silver-soldered joint in one of the metal parts.

All fuel pressure gages are panelboard-mounted. Each pressure line to a gage is fitted with a flush valve next to the gage, to facilitate loop cleanup and flushing operations. The pressure drop across the test housing is measured by means of a differential-pressure gage of a type that is protected internally against overpressuring.

g. Temperature Control and Measurement

The design criterion for loop temperature control was ±2°F at any control point between 70 and 90°F with ambient temperatures from 50 to 100°F. This criterion applies primarily to tests with recirculating fuel.

The heat exchanger chosen for the loop is a two-pass shell-and-tube unit with the fuel passing through the tubes and water or steam through the shell. Total heat exchange area is 26.2 ft^2. This exchanger is supplied with water, steam, or mixtures of the two; the steam supply is controlled manually, and the water supply is controlled by a valve that is actuated from a sensing element located in the fuel outlet line. Fuel temperature in the loop is monitored by means of a sensing element located in the test-section influent line (after contaminant injection) and a panel-mounted readout meter.

Preliminary calculations had indicated that the heat exchanger would meet the design requirements but with very little margin. The desirability of having a larger heat exchanger was apparent even in the early design stages, but excessively long delivery schedules on larger exchangers led to the selection of the present unit. In actual service, the performance of the heat exchanger has been as expected, but the overall performance of the temperature control system has been disappointing, mainly because of the excessive heating of the fuel in the pump. With wide-open water flow through the exchanger, it is barely able to keep up with the pump heating effect at a fuel flow rate of 20 gpm when using the small pump impeller. The original aim in the test program was to conduct all tests at a fuel temperature of 75°F. This proved impractical during hot weather, and the standard test temperature was subsequently raised to 80°F. During wintertime operation, the exchanger has ample heating or cooling capacity as required.

The accuracy of temperature control during a given test has been entirely satisfactory. Deviations of more than ±1°F are now very rare; deviations of up to ±3°F were encountered in early operation.

The problems encountered with heating of the fuel by the pump and the resulting marginal cooling capacity do serve to point out an advantage of injecting water (contaminant) at some location other than the pump. Any test loop may operate with considerable heating of the fuel in the pump, either because of pump overdesign or because of operation of the loop at fuel flow rates far below the design range. Injection of water into the fuel pump suction (as specified in MIL-F-8901A) may cause the fuel-water mixture to go through a temperature cycle as it passes through the loop. This may well lead to a "thermal cloud" effect, i.e., water haze formed by condensation of dissolved water, and this in turn will have an effect on test severity, probably a variable effect depending on ambient temperature. From this point of view, a strict control of fuel temperature ahead of the water injection point, as is the case in the Al/SS loop, is preferable.

h. Auxiliary Equipment

Connections are provided in the 1-in. high-velocity flow line after the test section for installation of any auxiliary equipment desired. This arrangement was intended primarily for testing different types of contaminant detectors or secondary cleanup devices. Thus far, no such equipment has been installed or tested. It is planned to install a clay-cartridge filter for treating base fuels prior to test. This will probably be installed either after the cleanup filter-separator or at the auxiliary equipment connections.

3. ADDITIVE INJECTION SYSTEM

Means are provided for metering and injecting additives into the main fuel pump suction line. Two separate stainless-steel systems are provided, the smaller designed for fuel corrosion inhibitors and the larger for fuel system icing inhibitor (FSII). The systems are sufficiently flexible in operation to handle any other types of additives or materials to be injected and blended at low concentrations. A wide range of metering rates is provided, more than sufficient to cover the extreme ranges in concentrations and fuel flow rates. The following comparison is based on injecting an additive at a rate corresponding to its final use-concentration in the fuel, i.e., single-pass line blending:

	Injection rate, ml/hr	
	Minimum	Maximum
Corrosion inhibitor:		
4-20 lb/1000 bbl; fuel flow, 15-60 gpm	42*	840*
Range available from equipment	23	8,100
Fuel system icing inhibitor (FSII):		
0.05-0.15 vol %; fuel flow, 15-60 gpm	1,703	20,440
Range available from equipment	651	26,100

*Approximate values based on average density.

These systems are shown schematically in Figure 5. Under normal loop operating conditions, the Zenith gear pumps used for injection will give precise metering of any liquid, even a thin liquid, since there is little or no back pressure at the injection point into the main fuel line.

Operating experience with the additive injection system has been very satisfactory. It has been used for successive blending of corrosion inhibitor and FSII in a large number of loop tests and also for blending nonstandard additives and contaminants. In the normal successive blending operations, it is convenient to dilute the corrosion inhibitor with test fuel to the same volume as that of the FSII; then, the "large" system is used successively on the two additives without change in injection rate. The loop system is set up for recirculation with one tank of fuel, and each additive is injected at a rate corresponding to the final use-concentration. Thus, for tests with a 600-gal fuel supply, recirculating at 40 gpm each additive is injected over a 15-min period. Following the additive injection, test fuel is flushed through the additive system in order to recover all the additive and bring it into the main fuel blend. After both additives have been injected, about 15 min of additional recirculation, or one complete turnover of the tank contents, is needed to ensure complete blending. Although the fuel-additive mixture should be very thoroughly homogenized in the pump, concentration differentials will continue to exist in the tank until injection is finished and the fuel blend is further recirculated. The very accurate injection rates provided by this equipment are not essential in recirculation blending. However, this accuracy was built into the design so that the system could be used for in-line blending at any fuel flow rate within the capabilities of the loop. For example, fuel can be pumped from one 15,000-gal underground tank through the loop and into another tank, simultaneously injecting additives at the desired concentrations and passing the freshly blended fuel through a filter-separator or other unit being tested. At a 20-gpm flow rate, this would provide over 10 hr of continuous, single-pass operation.

The additive injection system normally operates against little or no back pressure from the main fuel line. However, if it were desired to inject additives into a pressurized fuel line, the injection pumps are capable of precise metering into lines at 100 to 200 psig, so long as the additive being metered is reasonably viscous. Under these conditions, most corrosion inhibitors would be expected to meter satisfactorily, but FSII probably would not.

The additive injection lines have been kept as small and short as possible to minimize additive holdup and flushing requirements. The corrosion inhibitor injection system would require replumbing with larger tubing if used with viscous additives at injection rates in the higher range of pump capabilities.

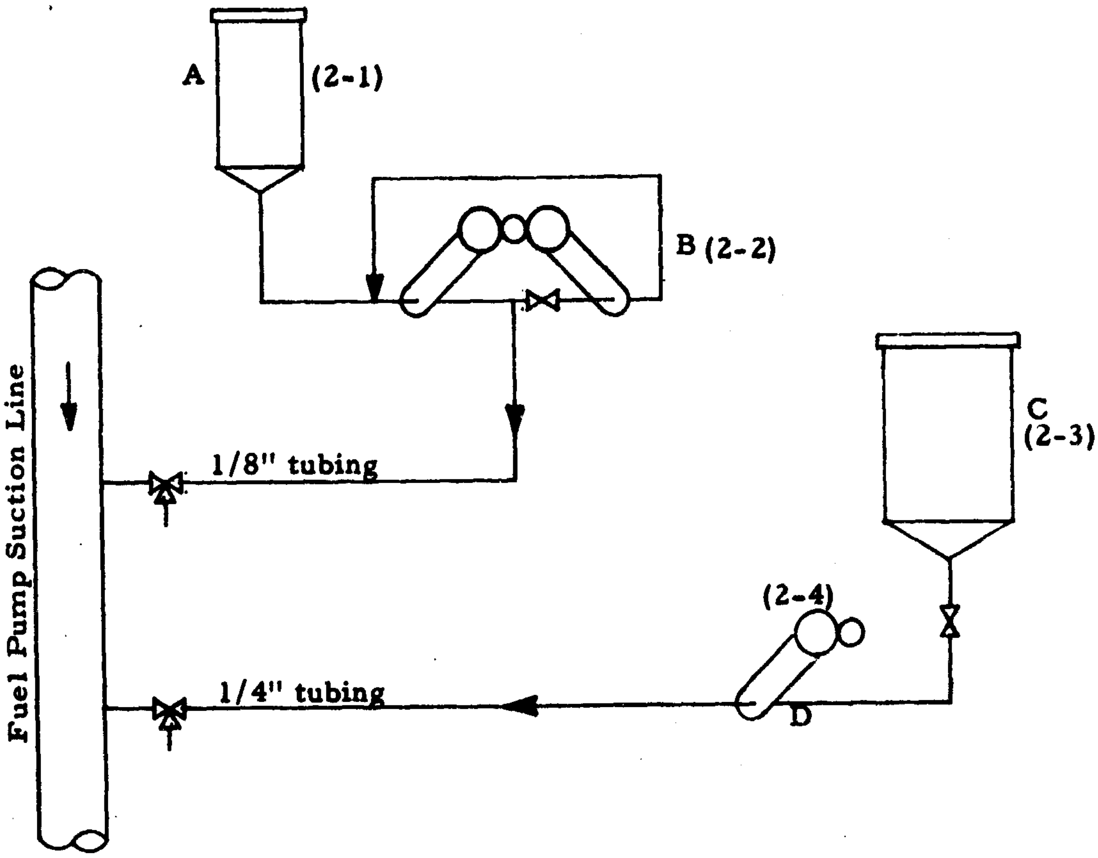


FIGURE 5 . ADDITIVE METERING AND INJECTION SYSTEM

A. Corrosion inhibitor supply tank, capacity 1 gal.

B. Corrosion inhibitor metering system, consisting of two No. 1/2 Zenith Type B gear pumps arranged for single-pump or differential delivery, with variable speed drive and common drive pinion; metering rates 23.4 to 8030 ml/hr. The higher rates in this range require parallel operation of pumps instead of single-pump or differential arrangement shown above.

C. FSII supply tank, capacity 6 gal.

D. FSII metering pump, No. 3 Zenith Type B gear pump with variable speed drive; metering rates 651 to 26,100 ml/hr.

4. WATER INJECTION AND MIXING SYSTEM

In most filter-separator test loops, the water injection system consists simply of a connection from the water main, a manual control valve, and a flowmeter. The system will also include a reserve tank if "water slug tests" are to be run, and it may include a booster pump and water filter, depending on the water-main pressure and water quality. Mixing of the water with the fuel is normally accomplished by injecting the water into the fuel pump suction line, although the use of a mixing screen is an allowable alternate in MIL-F-8901A testing.

In the design of the Al/SS loop, it was necessary to make the water system considerably more elaborate becuase of the intended use of the loop in broad-scale research and development work. In particular, it was established as a design criterion that the water system should be capable of preparing, metering, and injecting artificial water blends containing any or all of the following: (a) FSII up to 40 to 60%, (b) chloride up to 1000 mg/liter, and (c) acids to bring the pH into the range of 3.0 to 4.0 or even lower. All of these represent "water bottoms" that have actually been encountered in field fuel handling operations. The limits on water injection rate were set originally at 0.0015 to 6.0 gpm, representing a water/fuel mix from 0.01 to 10% water at fuel flow rates from 15 to 60 gpm. The limits of 0.01 and 10% are the extremes specified in MIL-F-8901A testing and also represent reasonable extremes for development work. The design range was later narrowed to 0.0015 to 1.8 gpm because of difficulties in designing the metering equipment and plumbing to cover the wider range. This range covers all test conditions from minimum water injection (0.01%) up to 3% water at any fuel flow rate within the design range. Tests with 10% water injection could be run at fuel flow rates up to 18 gpm, or possibly at 20 gpm, depending on the water injection pressure required.

The selection of materials for the water system presented some unusual problems. The combination of low pH and high chloride concentrations eliminates all common metals and restricts the selection of certain Hastelloys and other special alloys. The system design was started on that basis, and in fact the rotameters are Hastelloy-fitted. However, it was found entirely infeasible to obtain a suitable water pump within a reasonable time with such restrictions on materials. Therefore, the design criteria were relaxed to permit the use of 300-series austenitic stainless steels. This means that the system is <u>not</u> suitable for long-term service with low-pH, high-chloride water compositions. However, it can be and has been used in short-term runs on such water without any ill effects. It has also been used with high-pH water, which does not create any problems whatever in the water system.

The other problem in selection of materials arose in connection with the water injection pump, after it was decided to use a screw-type pump with rubber stator. Buna N rubbers are completely unsuitable for use with high

concentrations of FSII. After compatibility tests had been run on several rubbers by the pump manufacturer, natural rubber was selected for the stator.

The water blending and injection system is shown schematically in Figure 6. The booster-pump system was intended to maintain adequate water supply pressure for direct injection into the fuel line and also for feeding the main heat exchanger. However, any drop in water-main pressure in this particular location is usually so drastic that water will not even feed to the booster pump. Such loss of water pressure had occurred often enough in the past that it was decided not to rely on water-main pressure for injection at any time, and, accordingly, the direct-injection line (dotted line in Figure 6) was eliminated. When using tap water for injection, it is fed through a pre-filter into the supply tank and picked up by the injection pump.

The water supply and blending tank is an ordinary 55-gal polyethylene drum with cover and fittings for the inlet and outlet lines. The cover can be removed to insert a portable stirrer to aid in water-blending operations. The screw-type injection pump (described previously) picks up the water from the blending tank and delivers it to the final filter and metering system, the excess being returned to the supply tank via a backpressure regulating valve. The injection pump is rated at 3.1 gpm against 70-psig back pressure, when driven at 450 rpm.

The three water rotameters cover the entire range from 0.0015 to 1.8 gpm without changing floats. The injection end of the plumbing includes a check valve and vent line that can be used while setting flow rates prior to test.

The final water filter contains a stainless steel element rated at 1.5 μ for 98% retention, or 15 μ absolute. The use of a metal element minimizes the carryover of water contaminants from test to test, particularly in cases where surface-active materials are added to the water for test purposes. Even with this system, however, after accidental contamination with a detergent cleaning compound, the surfactant effects persisted through several tests and extra flushes.

The water blending and injection system has given highly satisfactory service. The only serious operating problem occurred in early operation, when the system was operated without a check valve at the injection point. Fuel backed up into the injection pump during a shutdown of the water system, and the natural-rubber stator of the pump was damaged seriously and had to be replaced.

After the water is injected into the main fuel line, the mixture passes through a screen to disperse the water. In designing the Al/SS loop, it was

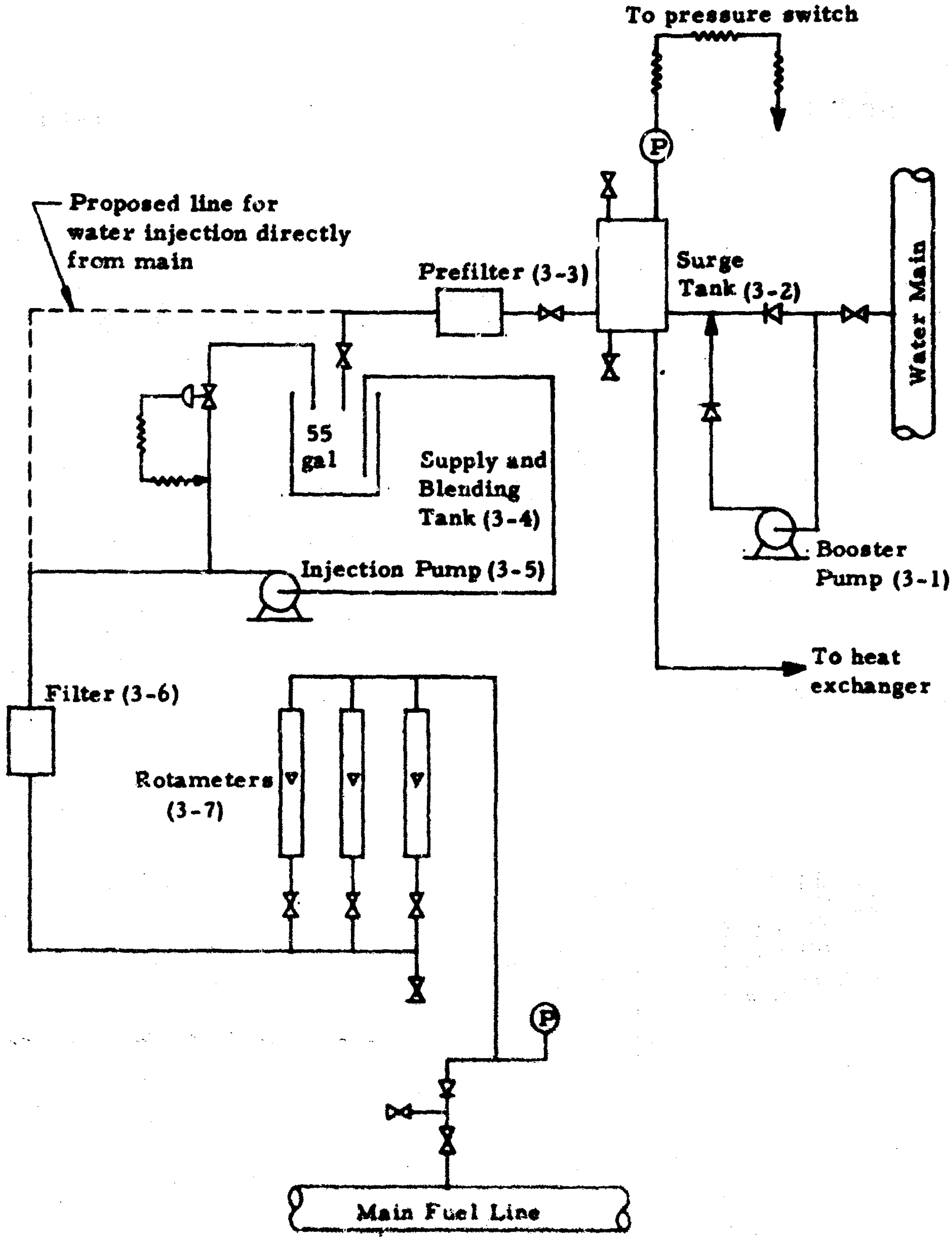


FIGURE 6 . WATER INJECTION AND MIXING SYSTEM

decided that the use of a mixing screen is more desirable than depending on mixing fuel and water in the fuel pump. With a screen, the degree of mixing can be defined in terms of screen dimensions and flow parameters. When mixing by injecting water into a pump suction line, the degree of mixing is peculiar to the given system and cannot be defined or readily duplicated in another system. Further, it appears probable that pump condition plays an important part in mixing efficiency. Finally, the temperature-cycle effects discussed previously may well interfere with test repeatability when mixing in the pump.

The use of a mixing screen is allowed as an alternate in MIL-F-8901A, which calls for a 100-mesh screen with a minimum area of 120 in^2, without regard to fuel flow rate. Based on previous experience in single-element tests, it was concluded that the screen area should be much smaller in order to give efficient dispersion of the water in the fuel. Also, it is only logical to make the screen area proportional to fuel flow rate so as to give comparable degrees of dispersion at any flow rate. A ratio of 0.112 in^2 of screen area per gpm of fuel flow was adopted as a design basis for the Al/SS loop*. A housing and three interchangeable screens were designed and fabricated. Design details are given in Appendix B. The assembly is designed for easy removal from the fuel line for cleaning or replacing the screen. The three 100-mesh screens were designed for the following fuel flow rates:

20 gpm - 2.2-in^2 screen area
32 gpm - 3.6-in^2 screen area
50 gpm - 5.6-in^2 screen area

From these screens, one can be selected for any fuel flow rate from 15 to 60 gpm to give an area/flow ratio approximating 0.11 in^2/gpm, in all cases between 0.08 and 0.15 in^2/gpm. Closer matches across the whole range of flow rates could be provided by a larger number of screens. Since almost all of the test work in this loop has been run at 20-gpm flow rate, the small screen provides a match for the 0.112 ratio.

It should be noted that this ratio is far lower than would be obtained using the 120-in^2 screen area specified in MIL-F-8901A. Even in 600-gpm tests, such a screen would give a ratio of 0.2 in^2/gpm.

Design calculations indicated that the pressure drop across the screens used in the Al/SS loop would be very small in terms of the pressure available, amounting to less than 1 psi.

*The ratio of 0.112 in^2/gpm was calculated from the screen area of a basket strainer that had been found to give good water dispersal with very little pressure drop in another single-element test loop.

The water is injected into he fuel in the 1-in. high velocity section, where the flow is highly turbulent. Turbulent flow persists through the screen housing. The screen breaks up any coarse drops of water and facilitates furthe- dispersal of the water during flow through the remainder of the 1-in. pipe leading to the test section.

Operating experience with the mixing screen has been good. The mixing action is efficient, producing fine water-in-fuel dispersions. The pressure drop across the screen is normally 1 psi or less, too low to read on the pressure gages available. Plugging of the screen is an occasional problem, even though the screen is cleaned routinely before each test. Ordinarily, when fresh fuel is recirculated through the cleanup filter-separator prior to test, there is no subsequent difficulty with screen plugging.

5. SOLID-CONTAMINANT MIXING AND INJECTION SYSTEM

The system designed for the Al/SS loop is similar in general plan to the systems used in regular MIL-F-8901A testing but has some added features for additional flexibility. In particular, a separate slurry-mixing system is provided so that very low concentrations of solid contaminants can be injected. A flow plan of the solid-contaminant system is shown in Figure 7. Materials for fuel-wetted components are aluminum, stainless steel, and Viton-type rubber, except as noted.

Before starting a discussion of this system, the terms "slurry" and "emulsion" should be defined, since there has been some confusion in the use of these terms in filter-separator testing. Here, we use the word "slurry" to denote any mixture of fuel with solid contaminants, whether very dilute or very concentrated, without the presence of any appreciable amount of free, undissolved water. When free water is present, the mixture is termed a "wet slurry." Such slurries, with or without water, would typically be rather thin, nonviscous materials, from which the contaminants would settle rather readily. The term "emulsion" is reserved for fuel-water mixtures that are stabilized by another component (which may be a solid contaminant) and are typically quite viscous. Thus, the mixture of red iron oxide, fuel, and water that is used in filter-separator testing is a "red iron oxide emulsion."

In the Al/SS loop solid-contaminant system, the dry dirt feeder, swirl hopper, and slurry injection pump are typical of systems used in MIL-F-8901A testing when injecting dry dirt such as AC test dust or red iron oxide. The fuel feeding this part of the system is metered at 15% of the total fuel stream over the entire range of main-fuel flow rates of 15 to 60 gpm. As noted previously, the system is arranged so that dry fuel is taken into the swirl hopper to pick up the dry dirt; this is the only deviation from MIL-F-8901A system criteria in this portion of the solid-contaminant system. The dry-dirt feeder is a conventional grooved-disk feeder that is rather too large for this type of testing; no satisfactory feeder is available in a smaller size.

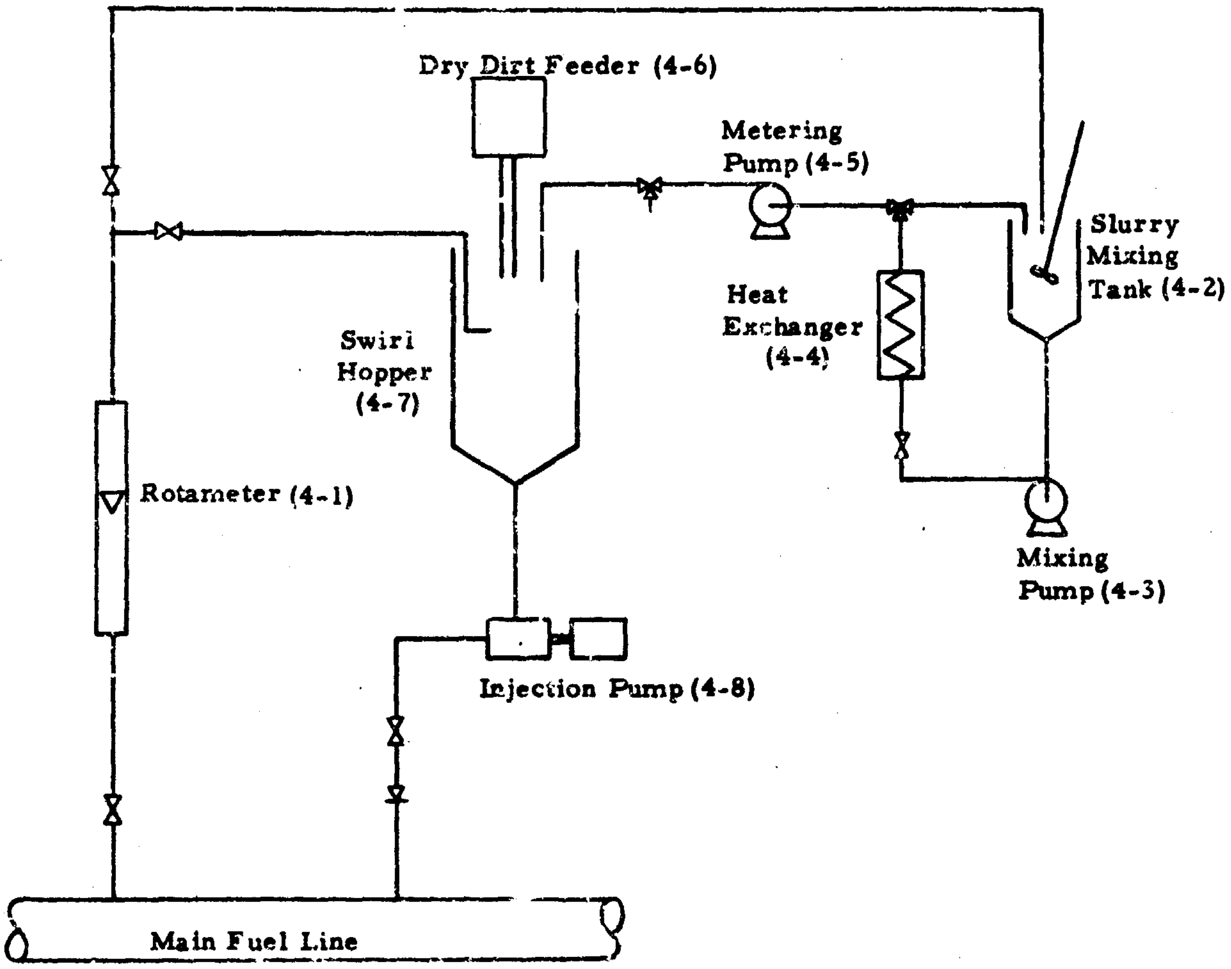


FIGURE 7. SOLID-CONTAMINANT SYSTEM

Typical feed rates for dry solid contaminants are 0.14 to 0.29 g/gal of fuel flowing in the main line; i.e., solids feed rates of about 2 to 17 g/min will cover the fuel flow rate range of 15 to 60 gpm. At the lower solids feed rates, the dirt feeder is marginal in accuracy and reliability. Efforts to obtain a more suitable dirt feeder have not been successful, and the problem was not judged important enough to warrant design and fabrication of special equipment. Using the present dirt feeder, recalibration before each run, and frequent maintenance are necessary for reasonably satisfactory operation.

The slurry injection pump is a screw-type, positive-displacement pump with rubber stator. This type of pump is widely used for this purpose and in fact is the only really satisfactory type when abrasive slurries must be pumped against relatively high pressures. It would have been desirable to use Viton-type rubber for this service, in line with the materials criteria of the rest of the loop. However, the pump manufacturer had found it impossible to mold Viton to the required dimensional tolerances. Accordingly, this pump was furnished with conventional Buna N stator. This is the only component in the entire loop where it was found necessary to deviate from the general criterion for elastomers in fuel-wetted components.

The remainder of the solid-contaminant system is designed primarily for metering and injecting low concentrations of contaminant in the form of a very dilute slurry. Specifically, it was anticipated that tests would be run at solid-contaminant concentrations of about 0.3 mg/liter in the main fuel stream, in line with typical solids contents of fuel being handled in the field. This would require contaminant metering and injection rates of 17 to 68 mg/min to cover the 15 to 60-gpm flow range, some two orders of magnitude smaller than can be attained with conventional dry-dirt feeders. Previous experience with another test loop had pointed out the difficulties involved in metering accurately at such low rates. Dry-dirt metering is simply out of the question with any type of commercially available equipment. Some preliminary design and fabrication work on miniature dirt feeders had not given any encouraging results. The only alternate approach is to batch-prepare a dilute fuel/solids slurry, and then meter this slurry into the main fuel line. Direct metering of even a dilute slurry against fuel line pressure introduces considerable difficulty. The system shown in Figure 7 was designed to meter the dilute slurry into an open swirl hopper, from which the injection pump pushes the material into the fuel line. The system consists of a 15-gal slurry mixing tank with a stirrer and recirculating pump to maintain the solids in suspension. The recirculating pump is an eccentric-rotary type with a Viton rubber shroud driving the fuel; pump capacity is 1.7 gpm at 30 psig. A cooler is installed in the circulating line to control fuel heating during long-term runs. Slurry is taken from the recirculating line to a slurry metering pump, which is a peristaltic (finger-type) pump operating on Viton tubing. The metering rate of this pump can be varied by speed control and by selection of tubing size. This pump meters the slurry into the swirl hopper, where it is picked up by the bypass fuel stream and injected into the main fuel line.

When used with dilute slurry, this system will provide long-term operation at low injection rates. For example, for the 0.3-mg/liter contaminant concentration mentioned earlier, about 11 gal of slurry containing solids in amount of 6.2 g/gal will suffice for a 16-hr test period at the maximum fuel flow rate of 60 gpm in the main loop.

The operability of the slurry mixing system with these low solids injection rates has not yet been tested thoroughly in practice, since the program, since the construction of the loop has not involved this type of testing.

The slurry mixing system is also designed to handle red iron oxide "emulsion" of the type used in certain tests under MIL-F-8901A. This emulsion consists of 0.1 lb of fine red iron oxide and 1 lb of 50-50 fuel-water mixture. The solids injection rate in such tests is about 2 to 8 g/min for 15-to 60-gpm main fuel flow. The system was used in four such tests at 20 gpm. The operation was not considered entirely successful, since the recirculation rates from and to the mixing tank were inadequate with this heavy emulsion. There was a pronounced tendency toward segregation of solids in the mixing tank. Another difficulty arose where the emulsion was fed to the swirl hopper for injection into the main fuel line. The emulsion did not disperse in the fuel, but tended to clump and stick on the bottom of the swirl hopper. It became necessary to drop the emulsion directly into the injection-pump suction line. This behavior of the red iron oxide emulsion does not denote any shortcoming of the system since in fact any injection system for emulsion of this type will be subject to problems with poor dispersion of the emulsion in the test fuel. In this system, such problems are simply more visible.

The slurry mixing system could also be used to meter solid contaminants in amounts that would normally be handled by dry-dirt injection. For example, in MIL-F-8901A testing, solid-contaminant injection periods are either 35 or 70 min, at rates corresponding to 2 to 17 g/min for the 15-to 60-gpm fuel flow rates. Such tests can be handled in the mixing system with slurries of about 160-to 320-g/gal solids content, varying the slurry metering rate to control the final solids content of the main fuel stream.

From this description of the solid-contaminant mixing and injection system, it can be seen that the system possesses maximum flexibility for specialized and varied types of testing in research and development programs, as well as the capability of conventional operation in MIL-F-8901A testing. Its flexibility has not been utilized to any great degree; the program subsequent to the construction of the loop has involved primarily dry-dirt injection. The system has certain limitations in handling thick materials of the red iron oxide emulsion type, but is believed to be no worse than most other systems designed for that specific purpose.

6. TEST SECTION

a. Single-Element Housing

Most of the work performed with the Al/SS loop has utilized an aluminum housing with a single MIL-F-52308 element and a PTFE-coated screen canister. This unit is shown in Figure 8. The canister is of the double-wall design developed for use with MIL-F-52308 elements. Coalesced water settles within the canister, passes out through openings in the canister base, and is drained from the bottom of the housing. As with all designs of this type, there is a "free passage" in the canister base for fuel flow until a water seal is built up. Therefore, at the start of a test, part of the fuel is bypassing through these openings in the base rather than passing through the screen. This creates the possibility of water droplet entrainment with this bypassed fuel, and such entrainment has been observed repeatedly in the first few minutes of a test. Such entrainment occurs primarily with JP-5 fuel rather than with the lighter and less viscous JP-4.

Several view windows are provided in the test housing, including the one shown in Figure 8, but viewing conditions are poor because of the impossibility of lighting the interior adequately. Also, the action at the element surface is completely blocked from view by the canister.

This test section has been used in tests at 20 gpm, the generally accepted flow rating of MIL-F-52308 elements. At this rate, the maximum calculated vertical component of flow velocities is 0.75 ft/sec in the clearance between element and canister, 0.21 ft/sec in the clearance between canister and housing, and 0.13 ft/sec in the housing above the canister. The element/canister clearance velocity is a hypothetical value that has no bearing on real conditions, since the major flow in that area is radial rather than axial. The canister/housing clearance velocity, however, is a real value, representing the maximum axial velocity occurring at the top of the canister, where the entire fuel flow must channel through the annular area. There has been some concern that this velocity of 0.21 ft/sec is unduly low and that, therefore, the tests run with this housing are unduly mild. Axial velocities on the order of 0.5 ft/sec are often cited as typical of modern design in filter-separators. The following comparisons are of interest in this connection:

	Axial velocity, ft/sec
Early commercial design (ca. 1958) in clearance between coalescer elements and housing	0.25-0.38
Four-element Mil-Std, 50-gpm, 12.75-in. ID	
Clearance between canisters and housing	0.33
Housing above canisters	0.13

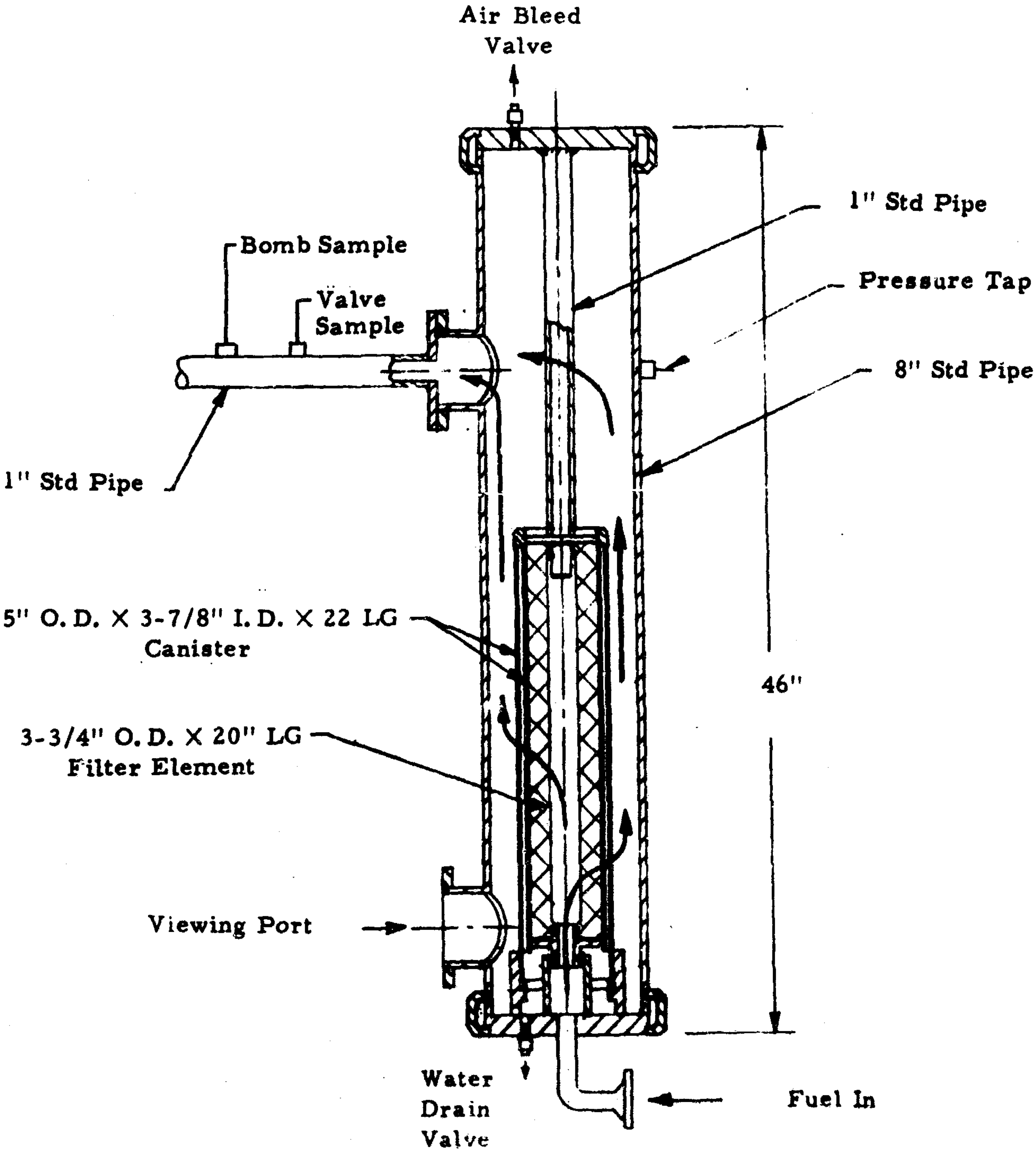


FIGURE 8. SINGLE ELEMENT TEST HOUSING

	Axial velocity, ft/sec
Single-element housing described here, 8-in. ID	
Clearance between canister and housing	0.21
Housing above canister	0.13

This comparison shows that the axial (vertical) flow velocities in the single-element housing are indeed somewhat low in comparison even with early designs of commercial equipment, and also in comparison with an early four-element design using military standard elements at a rating of 12.5 gpm each. It should also be noted that the disengaging space in the single-element housing above the element and canister provides a rather longer flow path than is common in commercial design. These factors could contribute to relatively mild conditions in this housing. However, a few tests run with a 6-in. insert within the 8-in. aluminum housing, giving about 0.5-ft/sec axial velocity in the clearance between canister and insert, failed to reveal any clear-cut effect on test severity.

It is probable that axial flow velocity will become an important factor in test severity only under conditions such that the separator screen or barrier stage rather than the coalescer element is the critical item in performance. Any clear-cut failure of the coalescer element will cause failure of the whole unit, regardless of the flow conditions in the canister and housing.

An interesting comparison is provided by calculating Stokes-law entraining velocities in JP-4 and JP-5 at normal temperature:

Water drop diameter, mm	Entraining velocity, ft/sec In JP-4	Entraining velocity, ft/sec In JP-5
0.1	0.0059	0.0016
0.3	0.053	0.014
1.0	0.59	0.16
3.0	5.3	1.4

It will be noted that entrainment of 1-mm water droplets becomes critical within the same general range of velocities that typifies filter-separator operation. It will also be noted that the drop diameter for entrainment is not extremely sensitive to flow velocity, and is in fact a square-root function. For example, in JP-4, decreasing the flow velocity from 0.5 to 0.2 ft/sec reduces the maximum diameter for drop entrainment only slightly:

0.5 ft/sec - 0.9-mm drops
0.2 ft/sec - 0.6-mm drops

If the drops are as small as 0.1 mm, decreasing the velocity is just not a practical method for reducing entrainment, since the entraining velocity in this case is only 0.006 ft/sec.

These numbers are purely illustrative and do not define the exact entrainment conditions in a filter-separator housing, where there are velocity gradients and a certain amount of turbulence. However, the numbers do demonstrate quite clearly the insensitivity of entraining-drop size to flow velocity and suggest that axial flow velocity is not a critical factor in most test results.

b. Transparent Housing

A transparent plastic housing was designed for testing elements under full-visibility conditions. This unit is shown in Figure 9. The acrylic plastic housing accommodates a single MIL-F-52308 element and a funnel-shaped flow guide with a PTFE-coated barrier screen at the top of the expanding flow section. This inner flow guide does not bear any pressure. Such a design was necessary since no practical way could be found to design a single transparent pressure vessel in this shape. Placing the barrier screen at the top of the unit permits direct viewing of the action at the element surface and also at the barrier screen surface, neither of which is possible when using a screen canister surrounding the element.

The relative area of the barrier screen is considerably less than in standard canister or basket designs. In the transparent housing, the ratio of screen area to fuel flow rate is 3.5 in^2/gpm, in comparison with 14 in^2/gpm for standard individual canisters and 5 in^2/gpm for certain single-basket designs in which one barrier screen encloses a number of elements. The latter ratio (5 in^2/gpm) is considered to be somewhere near the practical minimum for efficient operation, so the screen used in the transparent housing may be somewhat marginal. Also, from the viewpoint of practical operation, the horizontal position of the barrier screen is a disadvantage, since any water droplets collected at the screen surface do not have any chance to "roll off" or drain by gravity.

Vertical flow velocities in the transparent housing at 20 gpm are 0.37 ft/sec between the element and flow guide, 0.23 ft/sec in the flow guide cylindrical section above the element, and 0.09 ft/sec at the barrier screen. If the flow were uniformly vertical, then the gradually decreasing velocity in the expanding flow section could conceivably give a vertical classification of water droplets by size, and possibly even a stable level or levels of droplet suspension that could be used to rate droplet size and element coalescing efficiency. In actual operation, however, the observed behavior of the water droplets is quite different. With efficient coalescence by the element, the bulk of the water falls to the bottom of the housing immediately, and only a few droplets are carried up the "stem" of the funnel and into the

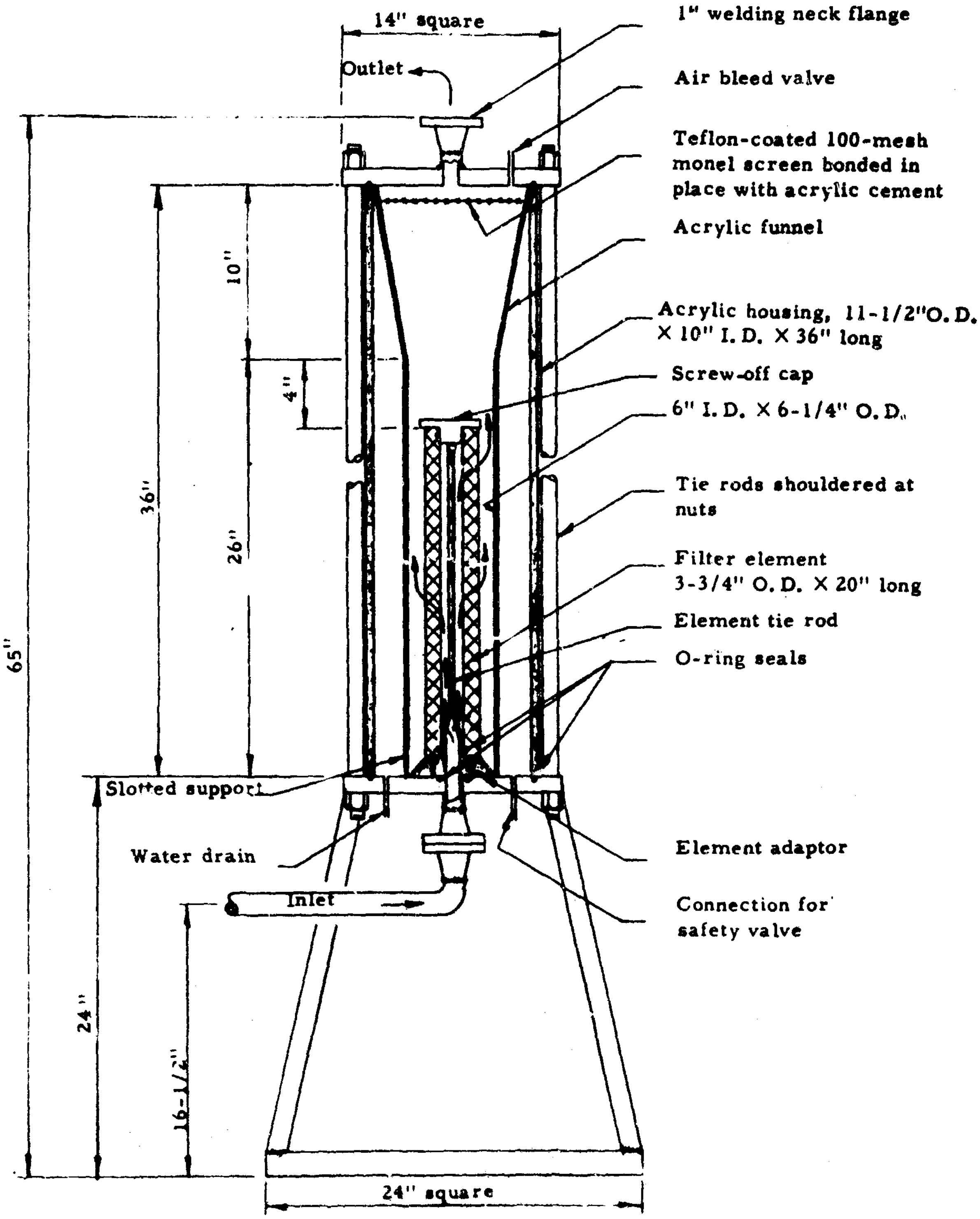


FIGURE 9. SINGLE-ELEMENT TRANSPARENT TEST HOUSING

expanding flow section. There is obviously a great deal of back-mixing in the expanding flow section; i.e., the droplets tend to follow circulation paths in a vertical plane and describe "loop-the-loop" paths of several inches. Sometimes a single droplet will follow such a path for a considerable length of time. From time to time, droplets impinge on the barrier screen and, in most cases, are deflected downward. Sometimes, after impinging on the barrier screen, a droplet will disappear from view and presumably either becomes attached to the screen or passes through. Above the screen, occasional passage of droplets can be noted. Viewing conditions above the screen are not extremely good, and it is impossible to correlate the passage of droplets with specific drop impingements from below.

When the transparent housing is operating under the conditions just described, analyses of the clear effluent fuel indicate traces of free water, presumably in the form of the droplets that had been observed in the housing.

The transparent housing has been used for observation of the behavior just described and also for observation of elements with special treatment or cutaway sections. It has not been found feasible to use this housing in the regular development program in the Al/SS loop, because of concern that the barrier-screen design and performance are marginal, and also because of mechanical problems.

The transparent housing is designed for a working pressure of 50 psig. This is not sufficient for regular use in the Al/SS loop program, since the supply pressure must be at least 70 psig to provide for frictional losses, element plugging to 40 psi, and operation of the flow controller. The transparent housing has been operated with 70 psig supply pressure without any gross failure. Initially, leaks at the end-seals were a problem. Also, after a relatively short period of operation, the outer housing has developed small cracks that cause concern as to the operational safety of the housing.

It would be quite feasible to design a new transparent housing with a straight flow section, suspending a standard canister screen from the top. Such a design would provide full visibility except downstream from (inside) the screen. However, regular use of a transparent plastic housing could not be recommended unless the loop flow control valve were relocated upstream of the test section so that the latter would operate under very little pressure.

7. CLEANUP FILTER-SEPARATOR

A four-element unit was specified and purchased from one of the major filter-separator manufacturers. This unit has a 16-in. aluminum housing with a gasketed top closure of the Victaulic type. It is equipped with four military-standard elements and individual PTFE-coated screen

canisters. At the full rated flow of 80 gpm (20 gpm per element), the vertical flow velocity in the canister-housing clearance is 0.24 ft/sec and in the top of the housing 0.136 ft/sec, i.e., generally on the low side of commercial design velocities. These low velocities, along with the excess capacity of the unit, provide reserve capabilities for cleanup:

Loop operating conditions	Cleanup F/S flow rating, % of actual rate	Flow velocity in canister-housing clearance, ft/sec
20 gpm (normal operations)	400	0.06
40 gpm (cleanup and blending)	200	0.12
60 gpm (top operational capacity)	133	0.18

The cleanup filter-separator has given satisfactory service. It has performed efficiently in all but a few tests in which the fuel contained enough surfactants, added deliberately, to disrupt the cleanup unit operation as well as that of the test unit. The cleanup filter-separator housing is rated at only 75 psig working pressure, and one instance of overpressuring and damage occurred during a fuel transfer operation. The only difficulty in normal operations is with the top closure, which is somewhat awkward to handle. In the program that has been carried out in the Al/SS loop, the cleanup filter-separator elements must be changed very often, and a more convenient top closure would have been desirable.

8. FUEL CLEANLINESS MONITORS

Two Bowser-Briggs Totamitors are installed in the main fuel flow line as cleanliness monitors. These instruments give a readout and continuous record of fuel clarity on the basis of forward light scattering. The instrument ranges are set so that the numerical values are nominally equivalent to ppm of free water. With this setting, the instruments are relatively insensitive to the presence of solid contaminants in moderate amounts.

The sensing units, installed directly in the fuel flow line, are mounted in 2-1/2-in. stainless steel housings. These units were supplied with sanitary pipe threads, and special adaptors had to be fabricated for installation in the main fuel line plumbing. Both units are installed vertically with fuel flowing upward. One is installed in the clean-fuel influent line after the heat exchanger and the other in the fuel effluent line leaving the test section.

The outputs of the sensing units are fed to amplifiers and fast-response recorders and readout meters at a remote location. The strip-charts from the recorders are extremely useful in detecting transient peaks in contaminant passage that are likely to be missed without such a record. No quantitative correlation can be made with free water and solids content of the fuel stream, since the Totamitor responds to both types of contaminant

and the readings are dependent on the degree of dispersity as well as the amount and type of contaminant. Nevertheless, the use of a continuous-monitoring instrument is almost a necessity in some types of test work and is a great convenience at all times.

SECTION III

TEST PROCEDURE

1. GENERAL

The test procedure used in all of the work reported herein is a modification of the inhibited-fuel test procedure specified in MIL-F-8901A. That specification, like its predecessors, includes several performance tests to determine the capability of a filter-separator for removing solid contaminants and water from fuel. Most of these performance tests are run with base fuel containing no additives; only the one test in the series is run with fuel containing a specified corrosion inhibitor.

Over the past 14 years, essentially all JP-4 jet fuel used by the Air Force has contained corrosion inhibitor conforming to MIL-I-25017, with the exception of certain periods when the use of such inhibitors was suspended. For the past 6 years, all Air Force JP-4 has contained fuel system icing inhibitor conforming to MIL-I-27686. This latter product, at least in its current version with very low glycerin content, has little or no direct effect on the efficiency of filter-separator performance*. Corrosion inhibitors, on the contrary, have been a major factor in filter-separator failures. All effective inhibitors in this class are surface-active materials, and all interfere to a greater or lesser degree with coalescence of water suspended in the fuel. Corrosion inhibitors also tend to disperse or peptize solid contaminants and hence may interfere with filtration efficiency.

The inhibited-fuel test specified in MIL-F-8901A is geared to the capabilities of present-day filter-separator elements. In particular, these elements cannot remove very fine particulate matter when it is thoroughly dispersed in an inhibited fuel. Therefore, the inhibited-fuel test in MIL-F-8901A is based on the use of a rather coarse solid contaminant, Standard Coarse AC Dust. Certain other tests in the 8901A sequence, using uninhibited fuel, are based on the use of a fine red iron oxide as the solid contaminant.

In view of the almost universal use of inhibited fuel by the Air Force, some sort of inhibited-fuel test is possibly the most important single criterion for rating filter-separators and elements for Air Force use.

*Fuel system icing inhibitor may be involved in certain current problems with plugging of filter-separator elements at low temperatures. However, this is not pertinent to the situation on testing the efficiency of filter-separators and is not discussed further in this report.

Much of the work in the program under which this report is written has been concerned with development of test procedures for rating corrosion inhibitors as to their effects on filter-separator performance.

For these reasons, practically all testing in the Al/SS loop has been performed using procedures applicable to inhibited fuels. The first such procedure, here designated "Procedure 10," is an adaptation of the MIL-F-8901A inhibited-fuel procedure to the Al/SS loop equipment, with certain changes intended to improve the operating and analytical techniques or to make the test more suitable for research and development work on fuels and additives. It should be emphasized that "Procedure 10" represents the initial attempt at modification of the MIL-F-8901A inhibited-fuel test procedure. Subsequent and more drastic modifications, aimed at a more realistic and/or a more severe test, will be discussed in future reports.

2. OUTLINE OF TEST PROCEDURE AND COMPARISON WITH MIL-F-8901A

Procedure 10 is based on the same general schedule specified in the MIL-F-8901A inhibited-fuel test: Water is injected for 60 min at 1% by volume of the fuel flow rate. Then, the water injection is continued at 1%, and coarse AC dust is injected at 0.00063 lb/gal (0.286 g/gal) until the pressure drop across the test unit reaches 40 psi. At this injection rate, the dirt loading reaches the nominal rating of 10-g/gpm rated flow within 35 min.

Criteria of satisfactory performance in the MIL-F-8901A inhibited-fuel test are effluent fuel cleanliness and adequate dirt-holding capacity. Effluent cleanliness is defined as "no undissolved water" and solids contents averaging not more than 0.5 mg/liter, with no single sample more than 1.0 mg/liter. Dirt-holding capacity is defined in terms of the pressure drop across the unit at the time the rated amount of dirt has been injected, i.e., after 35 min of dirt injection. A pressure drop exceeding 40 psi at 35 min, or a pressure drop reaching 40 psi in less than 35 min, is cause for rejection.

Although no rigid pass-fail criteria are appropriate in development work of the type reported here, the MIL-F-8901A criteria are useful as a standard of comparison. A problem arises in interpreting data on free water contents. In MIL-F-8901A, the contents of free or undissolved water in the effluent fuel samples are determined by Karl Fischer analysis for total water in each effluent sample and comparison of these values with the "clean-fuel" total water content, which in turn is compared with the water content of the fuel at saturation (equilibrium water solubility in fuel). This is an unsatisfactory scheme of analysis, because of the poor precision of the Karl Fischer method and certain anomalies in the sampling and water saturation methods.

For the purposes of this program, free water was determined directly by the AEL free water detector, which had been developed recently by the Aeronautical Engine Laboratory of the Naval Air Engineering Center. Although this method is still subject to some question as to absolute validity of the numbers obtained, it is clearly superior to the Karl Fischer scheme of analysis. As a general rule, free water contents between 0 and 5 mg/liter indicate very good operation of a filter-separator unit, contents between 5 and 10 or 15 mg/liter are not uncommon, and anything above 15 or 20 mg/liter is indicative of distress. No attempt has been made here to establish or even discuss pass-fail criteria, since this is a matter to be dealt with in the course of writing specifications, rather than in a development program.

Sampling schedules and analyses conducted under Procedure 10 follow the general outline of the MIL-F-8901A inhibited-fuel test, with certain additions. This subject is discussed further in Sections III-7 and III-8.

All tests in the program reported herein were conducted at 20-gpm flow rate with the single-element aluminum housing described in Section II, equipped with a double-wall PTFE-coated screen canister. A new military-standard element was used for each test.

MIL-F-8901A does not specify the type of housing or number of elements to be tested at one time, since it is written as a performance specification that is applicable to any type of filter-separator equipment. In element qualification or acceptance tests, an assembly with at least two elements is used, and Air Force practice requires tests in full-scale equipment. In the case of typical 600-gpm units, this requires thirty elements in each test if the 20-gpm flow rating per element is observed. For qualification or acceptance purposes, multiple-element testing is preferred to single-element testing, since the former gives a better statistical picture of element performance. In either single-element or multiple-element testing, any defective elements that will permit passage of large amounts of free water can be eliminated prior to installation by means of a coalescence-test check. However, a probllem does arise in single-element testing because of element-to-element variations in "tightness," which affects the dirt-holding capacity and in some cases the effluent cleanliness. In multiple-element testing, these variations are averaged out, for the most part.

For development work on either filter-separator elements or fuels and additives, the single-element approach has certain advantages. It can provide a direct measure of element-to-element variations that is absent in multiple-element testing. The smaller requirements for test fuel and size of test equipment constitute another advantage of single-element testing.

3. TEST FUEL

The proper fuel and additive to use in filter-separator testing have been a matter of some controversy and several shifts in thinking over the

past decade. Use has been made of VV-K-220 deodorized kerosine, as well as the service fuels, JP-4 and JP-5. The VV-K-220 deodorized kerosine is specified in MIL-F-8901A, but its use has been largely abandoned because of problems with cost, availability, and variations in quality. Although this is nominally a refined product, it is not required to meet any specification on demulsibility; therefore, it may vary widely in ease of water removal. The Air Force has used JP-4 in most element-acceptance testing, but is now tending to use JP-5. Qualification and acceptance of elements for centralized DoD procurements have been based on tests with JP-5 for several years. Both JP-4 and JP-5 specifications include a water separometer requirement and hence are at least partially controlled as to ease of water removal. Since JP-4 normally contains FSII and corrosion inhibitor as purchased, it is necessary to obtain additive-free JP-4 on special procurement for use in filter-separator testing.

Such uninhibited JP-4 fuel was used as base fuel in the tests reported herein. Inspection and procurement data are shown in Table 1. This fuel was purchased by the Air Force in January 1967, transferred to underground storage at Wright-Patterson AFB, and held for test purposes. Batches of this fuel were transferred to the two 15,000-gal underground storage tanks at the filter-separator test facility as needed. These tanks are normally used only for clean, uninhibited base fuel; the spent fuel after test is segregated in a scrap tank. Before accepting new base fuel, the tanks are drained thoroughly, and the entire system is flushed several times with new fuel. The JP-4 used in the tests reported herein is identified as Batch 14 and represents the second lot transferred to the facility storage tanks from the supplier's batch described in Table 1.

Water separometer (WSIM) tests were run periodically on the uninhibited JP-4 base fuel. At this time, WSIM values of 96 to 100 were obtained regularly.

4. TEST ADDITIVES

The choice of additives for use in filter-separator testing has been the subject of some controversy. Early work made use of Gulf 178, which is no longer a qualified MIL-I-25017 corrosion inhibitor. At present, the MIL-F-8901A inhibited-fuel test requires the use of duPont RP-2 corrosion inhibitor at a concentration of 20 lb/1000 bbl, the maximum allowable concentration for this particular inhibitor under MIL-I-25017. However, Air Force practice has been to use Santolene C at maximum concentration, 16 lb/1000 bbl. The Santolene C is used very widely in JP-4 procured for Air Force use, and its effects on filter-separator operation are commonly thought to be fairly mild in comparison with most other corrosion inhibitors.

For the development program involving the Al/SS loop, it was not necessary to designate any one corrosion inhibitor as "standard," since a

TABLE 1. SOURCE INSPECTIONS ON UNINHIBITED JP-4 BASE FUEL

	Inspection Results(a)	JP-4 Specification (b)
Gravity, API/60	55.2	45.0-57.0
Distillation: IBP, °F	126	---
10%, °F	192	---
20%, °F	224	290 Max.
50%, °F	300	370 Max.
90%, °F	420	470 Max.
EP, °F	506	---
% residue	0.5	1.5 Max.
% loss	0.5	1.5 Max.
Existent gum, mg/100 ml	0.6	7 Max.
Potential residue, mg/100 ml	1.8	14 Max.
Sulfur, %	0.122	0.4 Max.
Mercaptan sulfur, %	0.0005	0.001 Max.
Reid vapor pressure, psi	3.0	2.0-3.0
Freezing point, °F	-83	-72 Max.
Net heat of combustion, Btu/lb	---	18,400 Min.
Aniline-gravity product	7,756	5,250 Min.
Aromatics, vol. %	7.5	25.0 Max.
Olefins, vol. %	0.7	5.0 Max.
Smoke volatilty index	67.4	52.0 Min.
Copper strip corrosion rating	1-A	No. 1 Max.
Water separometer index, WSIM	96	70 Min. (c)
Water reaction, interface rating	---	1-b Min.
Thermal stability:		
Filter ΔP, in. Hg	0.0	3 Max.
Preheater rating	1	Below 3
Particulate matter, mg/gal, for f.o.b. origin	2.4	4 Max.

(a) Source inspection report dated 25 Jan 67, from Ashland Oil and Refining Co., Findlay, Ohio, Contract No. DSA-600-670-1231-Item 12a, on "JP-4 with no additives," Tank 183, Batch No. 7, quantity 421, 218 gal.

(b) MIL-T-5624G Amendment 1, dated 21 Nov 66.

(c) Applicable to fuel containing corrosion inhibitor.

large part of the program has been concerned with evaluating the effects of different corrosion inhibitors. However, the Santolene C has been adopted as more or less of a "baseline" for inhibitor effects, and more tests have been run with this inhibitor than with any other. Tests reported herein include fuel blends with minimum and maximum allowable concentrations of Santolene C and other qualified corrosion inhibitors.

In the inhibited-fuel test of MIL-F-8901A, the test fuel does not contain FSII. In this program, however, it was desired to use fuel equivalent to JP-4 handled in the field, and, accordingly, almost all tests have been run with test fuel containing 0.15 vol. % fuel system icing inhibitor, the upper limit of the specification range of 0.10-0.15%. The test data reported herein include tests both with and without fuel system icing inhibitor. It should be noted here that the fuel system icing inhibitor present in the fuel at the start of a test is largely removed from the fuel by water extraction during the test. With a 60-min period of water injection prior to the start of solids injection (as in the tests reported here), some 2/3 of the original additive is removed before the element ever "sees" any solid contaminant.

5. SOLID CONTAMINANT

The solid contaminant used in all of the tests reported here was Standard Coarse AC Dust, a siliceous dust with the following particle size distribution:

80-200 μ	6-12%
40-80 μ	27-33%
20-40 μ	20-26%
10-20 μ	11-17%
5-10 μ	9-15%
<5 μ	10-14%

The particle size distribution in the size range below 5 μ is not specified; however, the following data have been obtained on one sample of this dust:

3-5 μ	4%
2-3 μ	3%
<2 μ	5% (mostly 1-2 μ)

The fraction smaller than 5 μ consists of rather sharp, irregular particles. The fine fraction has been characterized as 65-70% plagioclase feldspar, 15 to 18% quartz, 10 to 12% amphibole hornblende, and minor amounts of micas and tourmaline.

This test dust is used in the MIL-F-8901A inhibited-fuel test. Dusts much finer than this are not retained successfully by present-day filter-separator elements when handling inhibited fuel. Much of the work in the

current program, subsequent to that reported here, has been directed toward the use of finer dusts to provide a more severe and discriminatory test for fuel additives. However, the results have shown that very little progress can be made in this direction so long as the test is geared to the use of currently available elements, which in turn are geared to and designed for passing the test with coarse AC dust.

6. WATER CONTAMINANT

For testing under MIL-F-8901A, any tap water may be used for injection as contaminant, provided it contains not more than 1.0 mg/liter of insoluble material and has a surface tension of at least 65 dyn/cm. The water pH is recorded but not limited.

The tap water available from the mains at Wright-Patterson AFB is hard well-water with no treatment except chlorination to 0.4 ppm gas injection. It has a total hardness of about 380 ppm and a pH of about 7.6. It had been used for a considerable amount of single-element testing prior to the work reported herein, and had offered no difficulties with excessive variations in pH or in meeting the requirements for surface tension and content of insoluble material, so long as a suitable filter was included in the supply line.

Data obtained during the earlier program had indicated that fuel blends containing certain corrosion inhibitors, including Santolene C, gave very much lower interfacial tension values when tested over this tap water than when tested over distilled water. This was attributed to the combination of sodium or other metal ions in the water with the organic-acid component of the corrosion inhibitor at the interface, thus lowering the interfacial tension. It had also been determined that municipal water supplies across the country vary tremendously in composition and pH. Particularly, with certain softening treatments, pH values over 10.0 may be obtained.

In view of these observations, it was decided to establish a synthetic water composition for use in this program. This makes it possible to avoid any "bias" that may be introduced into the test results by the use of extremely hard water, and also provides a reference water composition that can be duplicated by any laboratory for comparison of results. The use of a synthetic water composition also facilitates the study of variables in water composition and properties.

The water composition chosen for these tests contains the following ionic concentrations (in mg/liter):

Ca	36
Mg	8.1
Na	45

Cl	64
SO_4	32
HCO_3	119

This composition is a close match for "Type B" medium-hardness water, which is representative of water supplies derived from the Great Lakes and the St. Lawrence River. The concentrations of calcium, magnesium, and bicarbonate ions in the synthetic water are the same as those in "Type B" water. The sodium, chloride, and sulfate concentrations are slightly higher in the synthetic water than in the "Type B" water, but are well within the limits encountered frequently in natural water supplies. The synthetic water is blended from distilled water and stock solutions of reagent-grade chemicals, with the final concentrations as follows:

$NaHCO_3$	164 mg/liter
$CaCl_2 \cdot 2H_2O$	132 mg/liter
$MgSO_4 \cdot 7H_2O$	82 mg/liter

No problems are encountered in blending, and the cost of the synthetic water is not excessive. Even for a full-scale test of a 600-gpm filter-separator, the cost of the water and chemicals for a single inhibited-fuel test would not be more than about $40.

This water composition is identified as "Type B synthetic water" in the tests reported here.

It should be noted that more recent work has indicated that water quality is not as critical a factor in filter-separator test results as had been believed. Therefore, water standardization is not extremely urgent. The synthetic water composition can provide a convenient checkpoint at any time when it is suspected that water quality is influencing results significantly.

7. TEST CONDITIONS AND SEQUENCE OF OPERATIONS

All tests reported herein were run with JP-4 base fuel, with or without additives as indicated for the particular test. "Procedure 10" is described in the following paragraphs.

Tests are run with a single military-standard coalescer element and double-wall canister mounted in the single-element 8-in. aluminum housing described herein. A fresh element is used for each test. The canister and housing are cleaned and rinsed thoroughly between tests.

Standard test conditions are:

Fuel flow rate	20 gpm
Fuel supply pressure	70 psi

Fuel temperature entering test section	75°F

The 75°F temperature was maintained in the tests reported here, with some variations due to early control difficulties. Later, in summertime operation, it became impossible to hold 75°F, and the standard temperature was redefined as 80°F.

Standard contaminants are Coarse AC Test Dust and Type B synthetic water. Dry solid contaminant is metered and injected at 5.72 g/min, giving a 200-g loading in 35 min. Water injection rate is 0.2 gpm (1% of fuel flow rate).

The test schedule starts with 15 min of "pre-test" time with fuel flow but no contaminant injection. During this period, flow rates, pressures, and temperatures are adjusted as required. The start of the test proper (zero time) is the end of the pre-test adjustment period, when water injection is started. Water is injected from zero time to the end of the test. After 60 min of water injection, solids injection is started and continued until the pressure drop across the test housing reaches 40 psi. At this point, final samples are taken, and the test is terminated.

Either fresh base fuel or fuel from the preceding test may be used. The following step-by-step test procedure is used with fresh base fuel, starting with a clean system:

Weigh a new coalescer element to the nearest gram, and install it in the single-element aluminum housing, along with a double-wall canister.

Note: The element may be installed at any time prior to the start of the pre-test flow period.

Pump 600 ± 50 gal of clean base fuel through a suitable cleanup unit (outside the loop) and into one of the loop fuel tanks. Determine the amount actually charged by meter readings, tank gage glass level, and line and component holdup volumes established previously. All subsequent operations are performed using this one tank with recirculating fuel.

Circulate at 40 gpm through the cleanup filter-separator (bypassing the test housing) until the fuel is clean and dry as determined by Totamitor readings and sample analyses as required. The fuel temperature should be adjusted to approximately 75°F during this time.

Circulate at 40 gpm through the main fuel bypass (bypassing both the test housing and the cleanup filter-separator). Inject the required

amount of corrosion inhibitor over a 15-min period, then inject the required amount of fuel system icing inhibitor over a 15-min period and flush the injection system and lines with test fuel. Direct the main fuel flow through the cleanup filter-separator (but bypass the test housing), and continue to recirculate a minimum of 15 min at 40 gpm. Recheck the cleanliness of the fuel.

> Note: The preceding step is omitted when additive-free fuel is being tested.

Inspect and clean the mixing screen or install the screen if it has been omitted from the screen housing during the preceding operations.

Set the fuel flow rate at 20 gpm, set totalizing flowmeter reading at zero, and direct the fuel flow through the test housing and cleanup filter-separator. Recirculate for 15 min. During this "pre-test" period, adjust flow rates and temperatures, check operation of all instruments, take samples as required, and have the water injection system running and ready to direct the flow into the fuel line.

At the end of the 15-min pre-test period, start timing the run and direct the water flow into the fuel line. Take readings and draw samples as indicated in subsequent paragraphs. When the water level in the test housing covers the openings in the canister base, drain water at a rate that will maintain a stable level in the housing.

During the 60-min test period with water injection, prepare the solids injection system for operation and calibrate the dirt feeder, if this has not been done previously. Five min before the end of this 60-min period, direct fuel flow at 3 gpm into the swirl hopper, and turn on the solids injection pump; regulate the pump speed to maintain a stable fuel level in the swirl hopper.

After 60 min of test time, start the dirt feeder. Continue to inject both solids and water until the pressure drop across the test housing reaches 40 psi. At that time, cut off the water injection and dry-dirt feed, take final samples, and shut down the fuel flow.

Record test housing pressure drop and Totamitor readings every 10 min throughout the run, and also (a) 35 min after the start of solids injection (95 min of test time), (b) when the pressure drop reaches 20 psi, and (c) when the pressure drop reaches 40 psi. Totamitor readings are taken from the recorder charts after the run, and any peaks occurring between the regular readings should be noted. Record screen pressure drops, cleanup filter-separator pressure drops, and totalizing flowmeter readings approximately every 30 min of test.

Draw samples for analysis as follows:

Clean influent fuel - solids	Pre-test, 30 and 95 min.
Same - WSIM, IFT, and FSII content	Pre-test and 95 min
Effluent fuel - solids and free water	30, 95, and 130 min, and 20 and 40 psi
Injection water - solids	30 min
Same - pH and surface tension	30 and 95 min
Coalesced water - pH, surface tension and FSII content	30 and 95 min

Remove the coalescer element from the housing without losing any test dust, dry to constant weight, and record the weight to the nearest gram.

If the same fuel is to be reused in the subsequent test, analyze for FSII and reblend to the required level, then continue with the next test.

If the next test requires fresh fuel, pump the used fuel to scrap storage and drain the loop system thoroughly. Bring in base fuel (same as used for the next test) and circulate through the cleanup filter-separator at 40 gpm for 30 min; then, discard this fuel and drain thoroughly. Repeat with a fresh batch of uninhibited fuel, but this time bypassing the cleanup filter-separator. During this time, replace the cleanup filter-separator elements with fresh elements. Discard and drain the second flush. Then, bring in fresh uninhibited fuel and start the new test sequence as described previously.

The foregoing "Procedure 10" has been used essentially as described in the tests reported here and also in later tests. A few modifications have been introduced to improve the reliability of test results or to facilitate operations. For example, all new elements are now checked for coalescing ability by the coalescence test of MIL-F-8901A, using uninhibited base fuel. This makes it possible to weed out any really defective elements prior to the loop test. After the coalescence test, the element is flushed with fuel to remove most of the retained water, and then installed in the loop test housing without delay.

Another modification concerns the handling of the used elements after test. They are now rinsed in isopropanol and then petroleum ether to facilitate drying.

Other changes that have been introduced (after the tests reported here had been completed) are listed for the record.

Influent fuel temperature is controlled to 80°F (effective starting with Test 100).

With successive runs on the same fuel-additive composition, the loop is not flushed between runs; the system is drained thoroughly, after which fresh fuel is brought in and blended with additive (effective starting with Test 99). Also, cleanup filter-separator elements are not replaced between such runs on the same fuel-additive composition. When it does become necessary to remove cleanup elements to schedule a test on a different fuel-additive composition, the used elements may be saved, properly protected and identified, and again used in later tests on the same fuel-additive composition in which they first used.

Sample draw rates have been standardized, so that one-gallon bottled samples are drawn slowly (over about 2 min) to avoid excessive increases in flow rate through the element (effective starting with Test 100).

When a test is shut down at 40 psi or other specified pressure drop, the dirt feeder is shut off at once, leaving fuel flowing through the swirl hopper. However, water injection is left undisturbed until all fuel samples have been drawn (effective starting with Test 94).

8. SAMPLING AND ANALYSIS

Fuel samples are analyzed for content of particulate matter ("solids") by ASTM D 2276-65T, with minor modifications. The optional water rinse of membrane filters is never used in our tests. One-gallon bottled samples are taken for analysis. Filters are weighed on a Cahn electrobalance. A control filter is run with each test filter.

Analysis of injection-water samples for content of particulate matter has introduced some problems, since the membrane filters used to analyze fuels will tend to give very erratic results on water samples. This situation has been solved partially by the use of silver membrane filters of the same nominal pore size (0.8 μ). The filtration rates of water samples are extremely slow through either type of filter, and it has not been found feasable to use samples larger than 1 qt. The results from analysis of such small samples are nominally less precise than those from larger samples, but the improvement achieved by the use of the metal filters may compensate for part of this loss of precision. With the silver filters, no control filters and no special care in drying and cooling are required, since the

filters are not hygroscopic. The silver filters will not perform the same as the usual plastic membrane filters on fuel samples, where the plastic filters will retain fine particles that will pass freely through the silver filters. Presumably this difference is caused by static electrification effects with the plastic filters.

Free water contents of fuel samples are determined by line-sampling 500 ml of fuel through an AEL free water detector pad confined in a turbo fuel line sampler with perforated diffuser plate. The pad is then rated against color standards under ultraviolet light to estimate the free water content. The uranine-treated pads are prepared in the laboratory by SwRI personnel. Details on the equipment and techniques have been reported previously*.

Water separometer (WSIM) tests are run in accordance with ASTM D 2550-66T. At the time these tests were run, little had been done by way of investigating the questions of coalescer disk quality and others that have been raised recently. Qualitatively, it is known that, at the time these tests were run, consistent results in the 96-100 WSIM range were being obtained in tests on uninhibited JP-4 and JP-5 base fuels; this has not always been the case in recent months, and the discordant values have been fairly well identified with problems in disk quality.

Separometer tests were run in this program using distilled water (standard method) and injection water. These extra tests were run because of indications at that time that the water quality could be a critical factor in the interface properties of fuel-water systems.

Interfacial and surface tensions are run on test fuel and water using a duNouy ring tensiometer in accordance with ASTM D 971-50. The surface tension of distilled water is checked regularly to ensure that the instrument is functioning properly and the distilled water source is not contaminated. The surface tension of injection water is checked to guard against contamination of the water system, and in fact such contamination did occur during this test series. Interfacial tensions should give some measure of the degree of surface activity at fuel-water interfaces, but the values obtained by the standard ASTM method seem to bear little relation to coalescence properties. In this program, interfacial tensions of test fuel samples were checked with both distilled water and injection water. Certain fuel corrosion inhibitors tend to give very low interfacial tensions with natural waters in comparison with the values with distilled water.

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*Johnston, R. K., and Monita, C. M., "Evaluation of a Detector for Free Water in Fuel," Air Force Aero Propulsion Lab. Report AFAPL-TR-66-39, April 1966.

The fuel system icing inhibitor content of fuel samples is determined by differential refractometer, in accordance with FTMS-791a Method 5340. Water samples are analyzed directly by an adaptation of this method, omitting the extraction step.

SECTION IV

INITIAL OPERATING RESULTS

1. GENERAL

The results of the first thirteen tests performed with the Al/SS loop are reported here. Prior to these tests, loop and subsystem operation had been checked, and certain modifications of equipment had been made to provide smooth operation. The tests reported here were the first formal tests with the new equipment, and the operating personnel were unfamiliar with the loop operating characteristics and sampling schedules. Nevertheless, operations went rather smoothly, with no serious problems.

These tests were intended, first, to check the loop operation under actual test conditions, second, to familiarize personnel with the loop operating characteristics, and, finally, to provide initial data toward development of a valid short-term test procedure for rating corrosion inhibitors.

All of the tests in this series were run in accordance with the "Procedure 10" as defined in Section III. Each test consists of 60 min of water injection at 1% of the fuel flow rate, followed by simultaneous injection of 1% water and 286-mg/gal coarse AC dust until the test unit pressure drop reaches 40 psi. With a 20-gpm fuel flow rate, the respective injections are 0.2-gpm water and 5.72-g/min solids. The synthetic, medium-hardness water identified as "Type B synthetic water," which was described in Section III, was used in all except the first test. The base fuel was additive-free JP-4, which was blended with 0.15 vol % of MIL-I-27686D fuel system icing inhibitor and corrosion inhibitors for some of the tests. The corrosion inhibitors, all qualified MIL-I-25017B materials, included Santolene C at minimum and maximum allowable concentrations, and duPont AFA-1, Tolad 244, and Lubrizol 541 at minimum allowable concentrations.

2. TEST RESULTS

The results of the first thirteen tests are outlined in Table 2 and presented in more detail in Appendix A.

At the time these tests were run, the influent Totamitor had not yet been installed; the Totamitor readings in Appendix A refer to the Totamitor in the effluent fuel line from the test housing. These readings are not considered reliable, since the wrong type of sensing cell had been supplied with the instrument. The readings appear to be unduly low, and this was later

TABLE 2. SUMMARY OF INITIAL TESTS IN AL/SS LOOP

Test No.	Fuel [(a)]	FSII, vol %	Corrosion Inhibitor, lb/Mbbl	Time to 40 psi, min Total	Dirt	Worst Effluent, mg/liter [(b)] Solids	Free Water
48[(c)]	F	---	---	230	170	0.36	2-3
49	F	---	---	163	103	0.16	10-12
50	R	0.15	---	218	158	0.04	3-4
51	R	0.15	---	188	128	0.05	6-8
52	R	0.15	4 Sant. C	135	74	0.07	2-4
53	R	0.15	4 Sant. C	144	84	0.12	8-10
54	R	0.15	16 Sant. C	94	39	0.04	8-9
55	R	0.15	16 Sant. C	118	58	0.07	4-6
56	F	0.15	4 AFA-1	184	124	0.07	12-14
57	F	0.15	5.5 Tolad	(d)			
58	F[(d)]	0.15	5.5 Tolad	144	84	0.12	12-14
59	F	0.15	5 Lubrizol	163	103	0.33	3-5
60	F	0.15	---	138	78	0.03	1-2

(a) JP-4 Batch 14, fresh or reused from previous test.

(b) Worst values during normal operation. Results during upsets in operation and certain questionable results have been eliminated.

(c) In Test 48, filter water from Base water mains was used as injection water. In other tests, standard synthetic water was used.

(d) In Test 57, the pressure drop was 45 psi during the pre-test period, and the test was terminated without any water or solids injections. The same fuel, used in Test 58, was still considered fresh.

confirmed by direct comparisons. In the tests reported here, the only high Totamitor readings were obtained at the start of Test No. 49, when the test-housing bypass line was inadvertently left open during the first two minutes of test. This resulted in a full-scale deflection of the Totamitor when the wet, unfiltered fuel passed through the unit. Occasional Totamitor peaks were noted during the next 15 min, until the wet fuel had been completely worked out of the effluent side of the test-housing.

Other than this one incident, the only positive Totamitor indications were observed in Tests 58 and 59. The highest reading was 2, and this was associated with a free water content of 12-14 mg/liter. Based on subsequent experience, it is suspected that the Totamitor reading should have been higher.

As indicated in Table 2, fresh, uninhibited JP-4 fuel was used each of the first two tests. The fuel from the second test was subsequently inhibited with FSII and used in two more tests, then four tests with Santolene C. The FSII was brought back to 0.15 vol % before each of these tests. There was no makeup of Santolene C; i.e., the concentrations refer to amounts added initially. First, the fuel was inhibited with 4 lb/1000 bbl of Santolene C; and two tests were run; then, an additional 12 lb/1000 bbl was added, and two tests were run at a nominal total concentration of 16 lb/1000 bbl. For the tests on the other corrosion inhibitors, fresh fuel was used in each case.

3. OPERATING EXPERIENCE

No serious difficulties were experienced in initial operation. Sampling schedules were met, with only rare exceptions. Samples for solids and free water analyses were drawn every 10 min during the first two tests, after which the regular "Procedure 10" schedule was observed. The less frequent sampling under Procedure 10 presupposes continuous monitoring of effluent quality, so that reliable readings and records from a Totamitor or other instrument are a necessary part of the test data. From this point of view, the data obtained in these initial tests are subject to some question because of the apparently unreliable Totamitor readings. This situation has since been corrected.

No serious difficulties were encountered in temperature control. The deviations from the 75°F control point were not more than 3°F, and in most tests not more than 1 or 2°F. These tests were run during cold weather, and no difficulty was experienced in holding the fuel temperature down to 75°F.

The water-mixing screen plugged to a significant degree in several tests; pressure drops were as high as 7 psi. This can be avoided by the

inspection and cleaning schedules that have since been established and by omitting the screen when cleaning up the initial fuel charge prior to test.

Flow rate control was very good; the total throughputs indicated average rates of 20.0 ± 0.2 gpm in all full-term tests.

Some difficulties were encountered with dirt feed rates. The actual element weight gains were generally less than calculated amounts of dirt loading:

Test No.	48	49	50	51	52	53	54	55	56	58	59	60
Calcd., g	972	589	904	729	430	481	235	338	709	480	589	446
Gain, g	794	491	641	565	349	399	235	335	622	448	578	414

Since very little solid material passed through the test elements during these tests, any discrepancy between the calculated injection and the actual weight gain must be caused either by changes in dirt feed rate during the test or by losses of dirt from the element during removal, drying, and weighing after the test. Losses of dirt from the element cannot be large enough to account for some of the large discrepancies observed. It appears that the dirt feeder delivery rate dropped off during a given test. This situation had been fairly well corrected for the later tests in the series, and it can be seen that the agreement of calculated loading and actual weight gain data became reasonably good in the later tests.

Apart from the trouble with the dry-dirt feeder, there were no real problems with the injection systems for solids, water or additives. The water injection system apparently became contaminated with surface-active material, as evidenced by the low surface tension values obtained on the injection water, but this did not offer any operating problems and apparently did not influence test results. The surface tension values started at 70 dyn/cm in the first test using the synthetic water (Test 49) but dropped to 43 to 58 dyn/cm in Test 50. Occasional results in the 60-to 70-dyn/cm range were obtained in the next few tests, and it was not until Test 58 that values well above 70 began to appear. Actually, there were very few cases of surface tensions below 65 dyn/cm, which is the minimum specified in MIL-F-8901A. However, when using synthetic water blended from distilled water and reagent-grade chemicals, the surface tension should be at least 72 dyn/cm under most conditions, and the appearance of lower values can indicate only system contamination. Once the system is cleaned up properly, there are no further problems.

4. DISCUSSION OF TEST RESULTS

Among the tests reported here, there were no clear-cut failures in either coalescence or filtration efficiency. The effluent samples were particularly low in solids contents, mostly below 0.2 mg/liter. An initial value of 0.49 mg/liter in Test 49 was attributed to upset conditions, with the test-unit bypass line left open; a later value of 1.17 mg/liter in this test was attributed tentatively to a weighing error, since there were no other indications of solids passage. Free water in the effluent samples did not exceed 12 to 14 mg/liter in any of the tests and was below 10 mg/liter in all but two tests.

Since there were no clear-cut failures in coalescing efficiency, no attempt can be made to relate test results to water separometer or interfacial tension results on the respective fuel blends. The WSIM and IFT results are of some independent interest, since both distilled water and injection water were used in these tests. The following values include the standard test result with distilled water, using pre-test fuel, then (in parentheses) the results with injection water, using pre-test and 95-min fuel:

	WSIM	IFT, dyn/cm
No inhibitors	100	39 (39)
	100	42 (35)
FSII only	100 (--, 100)	-- (--, 29)
	98 (98, 100)	40 (40, 38)
	83 (90, 96)	42 (41, 42)
FSII and 4-lb Sant. C	91 (85, 79)	33 (18, 23)
	95 (75, 68)	36 (25, 28)
FSII and 16-lb Sant. C	80 (88, 75)	32 (12, 13)
	72 (74, 75)	28 (14, 16)
FSII and 4-lb AFA-1	94 (86, 84)	21 (19, 22)
FSII and 5.5-lb Tolad	88 (74, 35)	28 (14, 15)
FSII and 5-lb Lubrizol	83 (31, 25)	31 (25, 27)

Without corrosion inhibitors, the WSIM and IFT values were in the high ranges that are expected, with only scattered exceptions. The standard WSIM values, using distilled water in the test, were not reduced drastically by the corrosion inhibitors at the concentrations used here; the lowest value was 72 WSIM with

16 lb of Santolene C. However, when the separometer test was run with injection water, the Tolad 244 and Lubrizol 541 at their respective minimum concentrations gave very severe reductions in WSIM, to values as low as 25. The standard IFT values (distilled water) for the blends containing corrosion inhibitor were all within the range of 28 to 36 dyn/cm except for AFA-1, which gave 21 dyn/cm. Using injection water, the Santolene C gave extremely low IFT values, as did the Tolad 244. The Lubrizol 541 and the AFA-1 were less affected by the shift to injection water.

These results suggest that the effects of many corrosion inhibitors on interface properties are extremely sensitive to the type of water. Whether or not this will be reflected in filter-separator performance is another question. Subsequent work has demonstrated, at least for certain inhibitors, that their effects on filter-separator performance are not influenced appreciably by water properties. However, so long as interface effects are known to exist with certain combinations of inhibitors and waters, it will be desirable to use the same type of water in small-scale tests as is used in large-scale filter-separator evaluations, particularly if any correlations are to be attempted.

The data on the FSII contents of the fuels in these tests provide an interesting indication of the extent to which the additive is extracted from the fuel by the injected water. The degree of extraction may be calculated theoretically. The distribution coefficient of the additive between water and fuel phases is taken to be 200/1. Making certain simplifying assumptions, the calculated concentrations of the additive remaining in the fuel in tests run by Procedure 10 are as follows:

Minutes of test	0	30	60	90	120	150	180
Vol % additive	0.150	0.077	0.039	0.020	0.010	0.005	0.003

In the tests reported here, the 95-min concentrations ranged from 0.01 to 0.03% and averaged 0.018%, approximately the theoretical value; this indicates that the extraction efficiency is probably near 100%.

These data indicate further that, after 60 min of water injection, the FSII present in the fuel has been reduced to about one-fourth of its original amount. Thus, in the test schedule used here, the solids injection is not started until most of the FSII has been removed by extraction. It should also be noted that this 60-min period of water injection is in effect a pretreatment and water-wash, during which any water-soluble contaminants present in either the fuel or element will be extracted and drained off with the coalesced water.

One test in this series, Test 57, was terminated before it was really started. The pressure drop across the test housing exceeded 40 psi during the initial pre-test period, with only fuel flowing through the element. This was the first time such behavior had been observed. All elements in the tests reported here are from the same batch from the same manufacturer. The defective element was sectioned and inspected in detail, but the cause of its behavior could not be determined.

In the other tests, plugging times ranged from 39 to 158 min of dirt injection. A plugging time of 35 min corresponds to the injection of the rated amount of dirt, 200 g. Therefore, a plugging time less than 35 min would be considered a failure under the MIL-F-8901A criterion. It will be noted (Table 2) that there was less plugging (longer plugging time) for fuels without corrosion inhibitor. Of the corrosion inhibitors, the Santolene C at 16 lb/1000 bbl had the greatest plugging effect.

The plugging time and pressure-drop data provide a useful means of looking at test variability. Although the data reported here are too few for any detailed statistical analysis, some interesting comparisons can be made.

The pressure drop during the first 60 min of test could be influenced both by element construction and by fuel and additive properties. Data from the twelve full-length tests reported here have been analyzed with respect to pressure-drop behavior during the first 60 min of test. Mean values and standard deviations were calculated for the pressure drops recorded at each 10-min period. This information is shown in Figure 10, where curves are plotted for the mean and also for the mean plus and minus twice the standard deviation. The band would be expected to contain the results of 95% of a large number of tests identical to those reported here, assuming a normal distribution of data. At 60 min, this 95% band corresponds to results between 70 and 130% of the mean. These variations in pressure drop probably represent element-to-element variations in construction. Inspection of the individual data shows that some of the widest variations in pressure drop occur within the group of fuels containing no corrosion inhibitor, which should be comparable in pressure-drop and flow characteristics. Therefore, it appears that element variables rather than fuel variables are controlling these clean-element pressure drops.

It will also be noted from Figure 10 that the pressure drops tend to increase with test time during the first 60 min, when no solids are being injected. The increase from 0 to 10 min is caused mainly by the effect of the injected water, since the initial pressure-drop reading is normally taken before the water reaches the test element. The subsequent increases may reflect gradual accumulation of transient solids from the system and from the

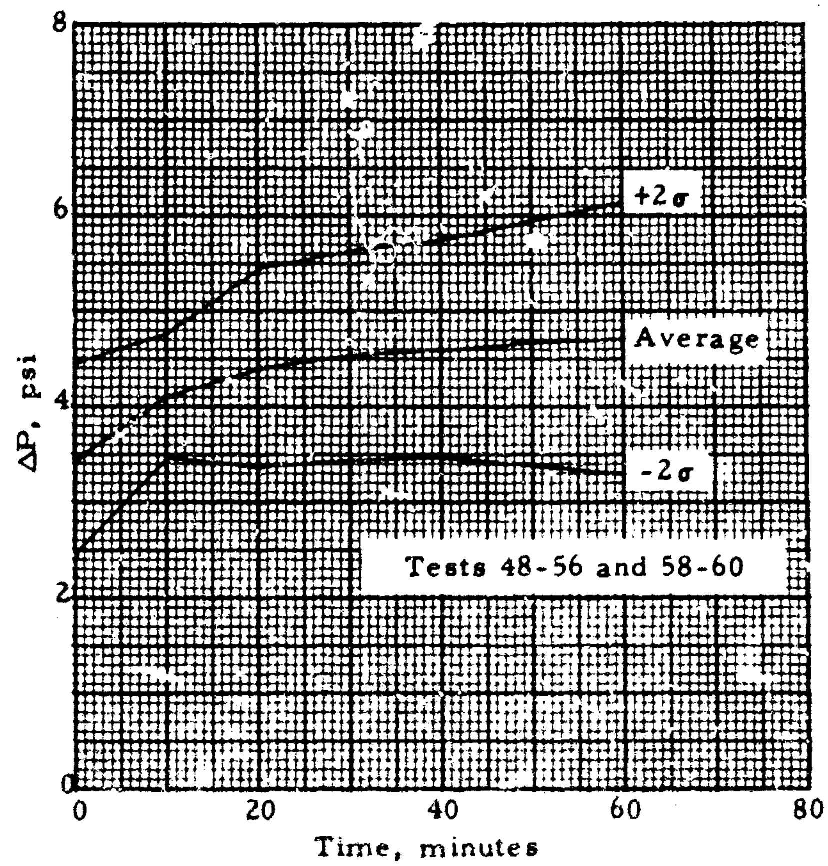


FIGURE 10. DIFFERENTIAL PRESSURE
DURING FIRST 60 MINUTES
(BEFORE SOLIDS INJECTION)

fuel, or they may reflect changes in media surface characteristics (e.g., because of surfactant adsorption), or in the "pore size" of the media.

The five tests in which no corrosion inhibitor was present should furnish a valid comparison of plugging behavior during the dirt injection period. Although anti-icing additive was present in the fuel used for some of these tests, most of it would be removed by extraction before any dirt is injected. For these five tests, the mean plugging time to 40 psi was 127 min, with a standard deviation of 34 min. This would indicate that 95% of a large number of identical tests would give plugging times between 59 and 195 min (between 46 and 154% of the mean). Such large variations in plugging time are indicative either of large element-to-element variations or large and uncontrolled variations in test conditions.

In this group of five tests, the plugging times are definitely related to the clean-element pressure drops. In the following comparison, plugging times refer to minutes of dirt injection to reach 40 psi, and clean-element pressure drops represent the first reading after water injection is started (10 min) and the reading at the start of dirt injection (60 min).

Plugging time, min	Clean-element ΔP, psi 10 min	60 min
170	4.0	4.3
158	4.0	4.0
128	4.3	4.7
103	4.7	5.7
78	4.6	5.5

As would be expected, the elements that are initially "tighter" do tend to plug faster when dirt is added. The good correlation obtained with these few data is probably fortuitous, but it does support the general conclusion that element-to-element variations are responsible for most of the scatter in plugging times.

In general, the corrosion inhibitors contributed to faster plugging of elements, but the scatter in the data make it impossible to draw any fine comparisons. The fuels containing corrosion inhibitor gave plugging times from 39 to 124 min, in comparison with a mean plugging time of 127 min (range 78 to 170 min) for the fuels without corrosion inhibitor. The clearest picture is given by the data on the Santolene C blends, where 4 lb/1000 bbl gave plugging times of 75 and 84 min, and 16 lb/1000 bbl gave plugging times of 39 and 58 min. This is illustrated in Figure 11, where the

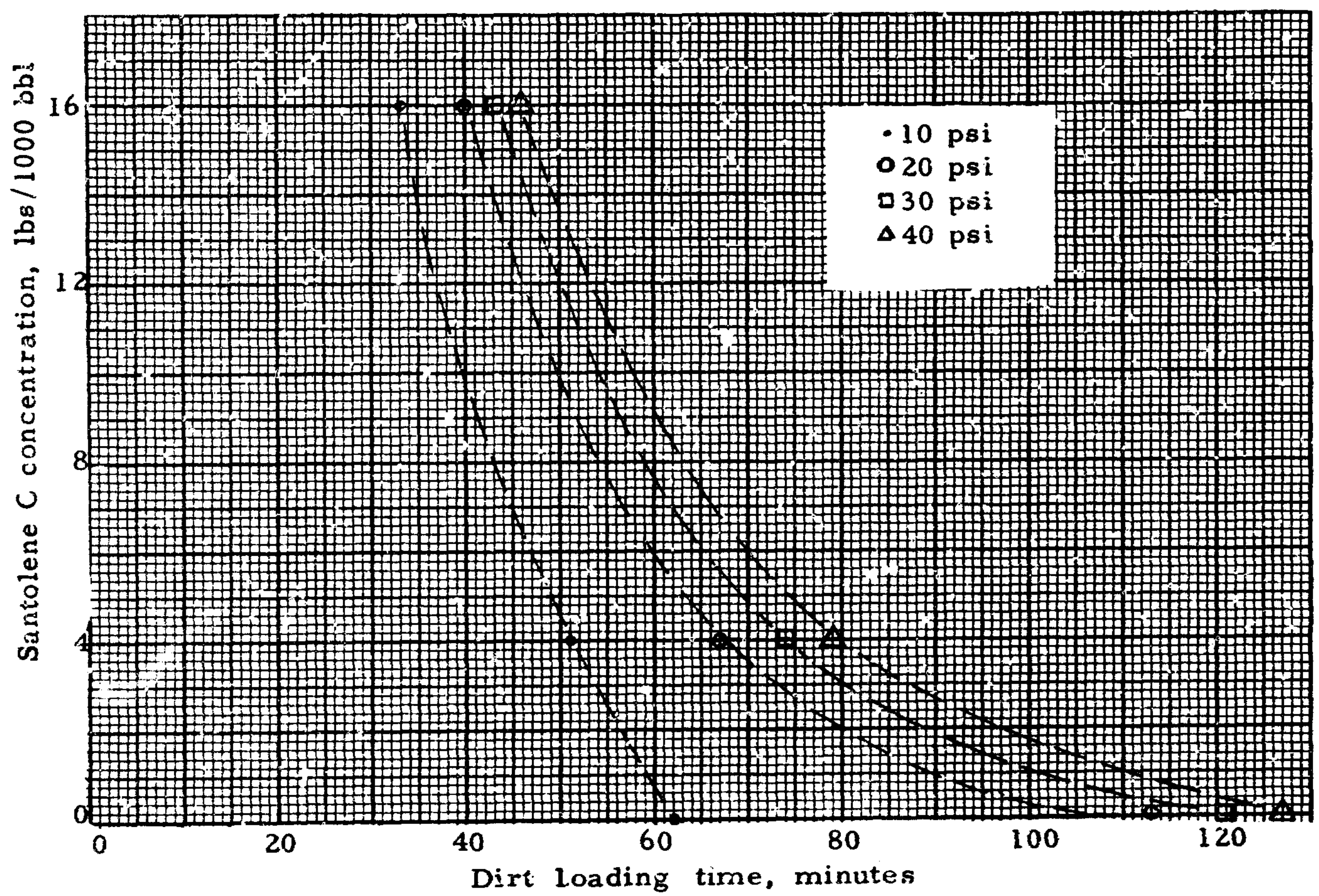


FIGURE 11. EFFECT OF CORROSION INHIBITOR ON DIRT LOADING TIME TO PRODUCE SELECTED DIFFERENTIAL PRESSURES

dirt loading time to 10-, 20-, 30-, and 40-psi pressure drop is plotted against concentration of Santolene C. These plots suggest that the minimum amount of Santolene C promotes element plugging to a considerable extent, and that further addition of Santolene C up to the maximum allowable concentration has relatively less effect in this direction. Obviously, these data refer only to the specific test conditions used here. Also, in view of the limited amount of data, the trend cannot be interpreted as a general index of the behavior of the additive.

All of the data discussed in this report should be regarded in the light of preliminary operating data on a new facility. Although the results are of some independent interest, they can serve only to point out probable trends, rather than to give definitive answers to the many problems that are associated with filter-separator element testing and the behavior of fuel additives.

SECTION V

SUMMARY AND CONCLUSIONS

This report includes information on the design, layout, equipment, procedure, and initial operating results for a new filter-separator test facility. This facility has been designed for maximum flexibility for use in research and development work on fuels, additives, and equipment. The test loop is designed for fuel flow rates of 15 to 60 gpm and can be used with any type of filter-separator or other equipment within this range. Special subsystems are provided for injection of additives, water, and solid contaminants. All fuel-wetted components of the loop consist of materials that are compatible with the newer types of high-quality hydrocarbon fuels. The major metals of construction are aluminum and stainless steel, and the major nonmetals are fluorinated rubbers and plastics. No copper-base alloys or carbon steels are used. Buna N type rubbers, which have very deleterious effects on the thermal stability of high-quality fuels, have been excluded from fuel-wetted service in all but one pump application, where no suitable alternate could be found.

The water mixing and injection system is designed to handle either natural or synthetic waters and is independent of the water-main supply. The system can handle waters containing high concentrations of organic solvents such as fuel system icing inhibitor or high concentrations of inorganic salts. High-chloride, acidic waters can be handled in short-term tests. The solid-contaminant mixing and injection system can be used in either dry-dirt or slurry feed operations and can be used to meter and inject very small amounts of contaminants.

Fuel cleanliness monitors, operating on a light-scattering principle, are provided in the influent and effluent fuel lines of the test unit, as a continuous check on fuel quality.

This test facility, which has been termed the "Al/SS loop," has been used primarily in a program aimed at developing valid single-element test procedures for rating fuel additives. Initial operating procedures followed the inhibited-fuel test procedure of the filter-separator performance specification, MIL-F-8901A, with modifications and improvements.

The first thirteen tests with this new facility are reported here. These tests have demonstrated that the loop and subsystems operate smoothly. No serious problems were encountered in initial operation, and no major modifications of equipment were necessary.

The initial operating results, on fuels with and without additives, indicate that the Al/SS loop does provide a means for evaluating the effects of

corrosion inhibitors and other additives on filter-separator performance. In these tests, there were no severe failures in either coalescence or filtration; the effluent fuels were relatively clean. The major differences observed among the different fuels were in the plugging rate at a given dirt injection rate. Corrosion inhibitors in general tended to increase the plugging rate. There was a considerable scatter in the plugging-rate data, and the results suggest that element-to-element variations are the major source of the scatter. The scatter is sufficient that little credence can be given to single test results.

The Al/SS loop has not yet been used in any handling studies with high-quality, thermally stable hydrocarbon fuels of the type on which the loop materials selection was based. However, the loop has demonstrated its operability and flexibility in other types of testing. It has been used in certain standardized filter-separator evaluation procedures and also in a fairly extensive program of procedure development for additive evaluation. This latter investigation (not reported here) has included studies of the effects of water composition and properties, solid contaminant type and particle size, test schedule and sequence of operations, and the like. The data obtained in these studies will be the subject of future reports and will be used in an attempt to develop statistically sound correlations between fuel and additive properties, test parameters, and filter-separator element design and construction.

APPENDIX A

TEST DATA SUMMARY SHEETS

TABLE 3. LOOP TEST NO. 48 Date: 13 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Mo[illegible] MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Filtered tap water[a] injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.

(x) Fresh-fuel blend OR ( ) Fuel from previous test		
Fuel system icing inhibitor, Dow, Lot 08186119	None	vol. %
Corrosion inhibitor	None	lb/Mbbl

Fuel inlet temperature, °F	75 ± 2	Fuel throughput, gal	5287[b]
Test duration, min	248	Avg. flow rate, gpm	20.1

Actual element weight gain, g	794
Calculated dirt loading, g	972

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.26	0.02	0.11
	WSIM, dist. water	100		
	WSIM, inj. water	--		
	IFT, dist. water, dyn/cm	39.4		
	IFT, inj. water, dyn/cm	38.6		
	FSII content, vol. %	0.00		
Injection water	Solids, mg/liter			0.2[c]
	pH			7.4[c]
	ST, dyn/cm			69.9[c]
Coalesced water	pH			8.4[c]
	ST, dyn/cm			--
	FSII content, vol. %			--

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	0	2	2	1	1	1	1
Cleanup ΔP, psi	--	--	--	--	--	--	--
Throughput, gal	--	--	--	--	--	--	5287

(a) Filtered tap water used in this test only.
(b) Total throughput for 15 min pre-test and 248 min test period.
(c) Post-test samples.

TABLE 3. LOOP TEST NO. 48 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.0	0.03		0
5	4.0	Neg	0	0
10	4.0	0.10	1-2	0
20	4.2	0.05	2-3	0
30	4.3	0.11	0-1	0
40	4.3	0.17	0-1	0
50	4.3	0.01	1-2	0
60	4.3	0.11	2-3	0
70	4.3	0.01	1-2	0
80	4.5	0.15	0-1	0
90	5.0	Neg	0-1	0
100	5.1	0.08	0-1	0
110	5.4	0.06	0	0
120	5.6	0.03	0	0
130	6.0	0.11	0	0
140	6.5	0.13	0	0
150	7.0	0.15	0-1	0
160	7.5	0.05	1-2	0
170	8.5	0.36	0	0
180	9.6	0.36	1-2	0
195	12.5	0.16	0	0
210	18.8	--	0	0
225	32.2	Neg	0	0
230	41.0	0.11	0	0
233	36.0			0

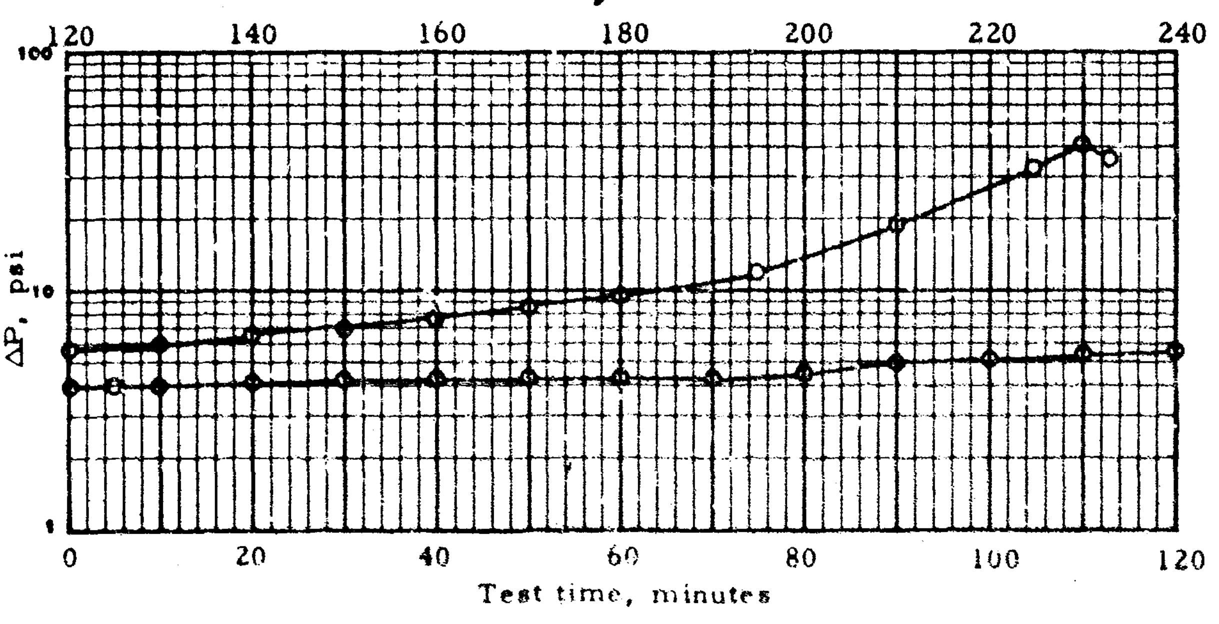


TABLE 4. LOOP TEST NO. 49 Date: 16 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
(x) Fresh-fuel blend OR ( ) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	None	vol. %
Corrosion inhibitor	None	lb/Mbbl

Fuel inlet temperature, °F	75 ± 2	Fuel throughput, gal	3377
Test duration, min	168	Avg. flow rate, gpm	20.1

Actual element weight gain, g	491
Calculated dirt loading, g	589

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.02	0.05	0.05
	WSIM, dist. water	100		
	WSIM, inj. water	--		
	IFT, dist. water, dyn/cm	42.4		
	IFT, inj. water, dyn/cm	34.7		
	FSII content, vol. %	0.00		
Injection water	Solids, mg/liter			0.04[a]
	pH			8.1[a]
	ST, dyn/cm			70.3[a]
Coalesced water	pH			8.1[a]
	ST, dyn/cm			--
	FSII content, vol. %			--

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	2	2	5	5	7	7	7
Cleanup ΔP, psi	0	0	0	0	0	0	0
Throughput, gal	207	812	1426	2034	2829	3424	3584

(a) Post-test samples.

TABLE 4. LOOP TEST NO. 49 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0[a]	4.6	0.49	0	100+[a]
5	4.6	0.04	--	0
10	4.7	0.07	0-1	0
20	5.0	0.16	1-2	0
30	5.0	0.01	0-1	0
40	5.4	0.10	1-2	0
50	5.4	0.08	1-2	0
60	5.7	1.17[b]	4-5	0
70	5.4	0.15	4-5	0
80	5.9	0.09	4-5	0
90	6.5	0.06	3-5	0
100	7.9	0.10	2-4	0
110	9.2	0.15	4-6	0
120	10.8	0.02	5-7	0
130	12.3	0.11	2-4	0
140	15.0	0.02	1-3	0
150	20.2	0.10	0-1	0
160	31.5	0.09	1-2	0
163	40.5	0.10	10-12	0
168	39.8			

(a) Test housing bypass line open during first 2 min of test. Between 5 and 20 min, about 30 short-term peaks appeared on Totamitor chart, maximum reading (peak height) 30.

(b) Probable weighing error; filter appeared clean.

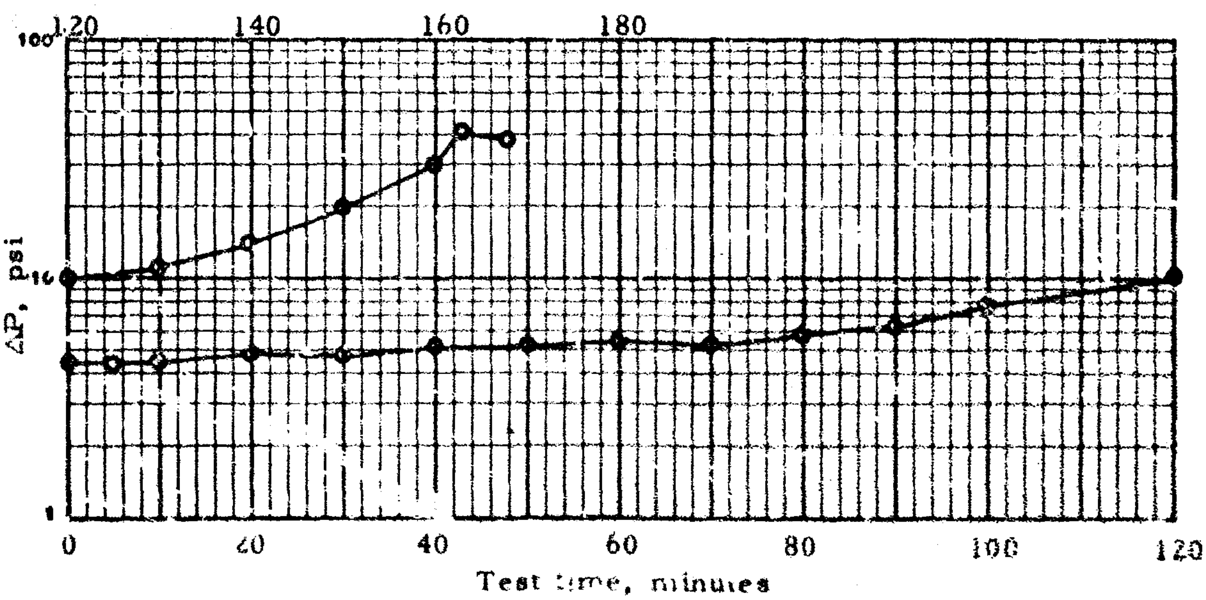


TABLE 5. LOOP TEST NO. 50 Date: 20 March 1967

Al/SS loop with 8" I. D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
( ) Fresh-fuel blend OR (x) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor	None	lb/Mbbl

Fuel inlet temperature, °F	75 ± 3	Fuel throughput, gal	4377
Test duration, min	220	Avg. flow rate, gpm	19.9

Actual element weight gain, g	641
Calculated dirt loading, g	904

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	--	0.03	Neg
	WSIM, dist. water	100		--
	WSIM, inj. water	--		100
	IFT, dist. water, dyn/cm	--		--
	IFT, inj. water, dyn/cm	--		28.8
	FSII content, vol. %	0.14		0.02
Injection water	Solids, mg/liter		1.3	--
	pH		8.2	8.1
	ST, dyn/cm		58.4	43.3
Coalesced water	pH		8.2	8.4
	ST, dyn/cm		53.9	61.4
	FSII content, vol. %		5.5	1.7

Time, min:	Pre-test	30	[illegible]	95	130	160	End
Screen ΔP, psi	2	2	2	2	2	2	2
Cleanup ΔP, psi	0	0	0	0	0	0	0
Throughput, gal	356	943	1540	2236	2939	3536	4733

TABLE 5. LOOP TEST NO. 50 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.5			0
10	4.0			0 (30-sec peak of 2 at 11 min)
20	4.0			0
30	4.0	0.04	3-4	0 (Minor "blips" at 21 and 35 min)
40	4.0			0
50	4.2			0
60	4.0			0
70	4.4			0
80	4.6			0
90	4.8			0
95	5.0	0.01	1-2	0
100	5.2			0
110	5.4			0
120	5.8			0
130	6.2	Neg.	2-3	0
140	6.8			0
150	7.6			0
160	8.5			0
170	9.6			0
180	11.4			0
190	14.4			0
200	18.0			0
203	20.0	0.02	2-3	0
210	26.0			0
218	40.0	0.04	2-3	0
220	43.2			

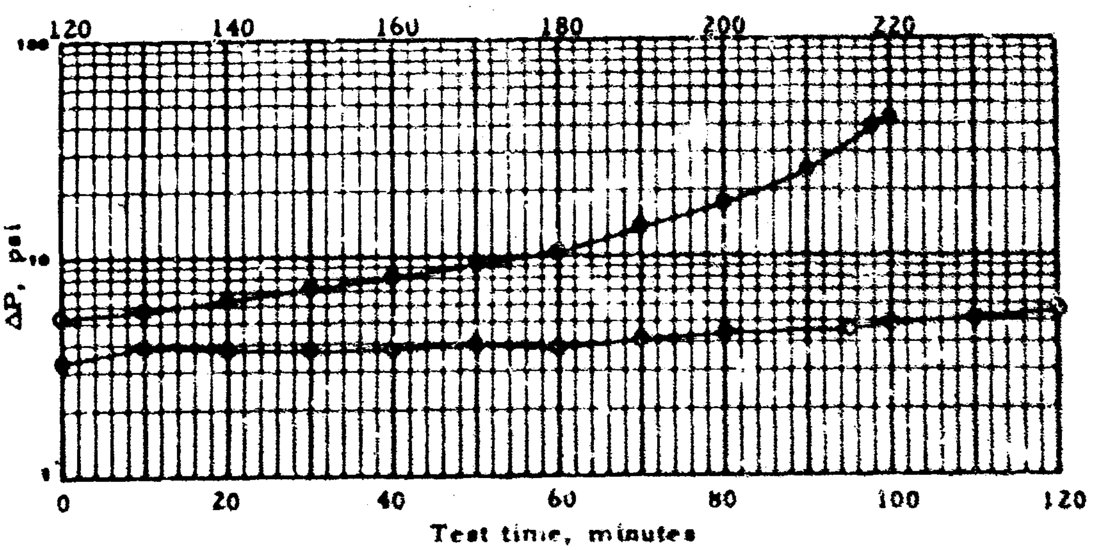


TABLE 6. LOOP TEST NO. 51 Date: 21 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
( ) Fresh-fuel blend OR (x) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor	None	lb/Mbbl

Fuel inlet temperature, °F	75 ± 1	Fuel throughput, gal	3792
Test duration, min	190	Avg. flow rate, gpm	20.0

Actual element weight gain, g	565
Calculated dirt loading, g	729

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	--	Neg	0.02
	WSIM, dist. water	98		--
	WSIM, inj. water	98		100
	IFT, dist. water, dyn/cm	40.1		--
	IFT, inj. water, dyn/cm	39.6		37.6
	FSII content, vol. %	0.14		0.02
Injection water	Solids, mg/liter		0.4	--
	pH		8.0	8.1
	ST, dyn/cm		61.9	59.6
Coalesced water	pH		8.2	8.3
	ST, dyn/cm		56.6	56.1
	FSII content, vol. %		4.5	1.7

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	2	6	6	6	7	7	7
Cleanup ΔP, psi	0	0	0	0	0	0	0
Throughput, gal	307	895	1488	2190	2898	3495	4099

TABLE 6. LOOP TEST NO. 51 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.0			0
10	4.3			0
20	4.4			0
30	4.5	0.03	0-1	0
40	4.6			0
50	4.6			0
60	4.7			0
70	4.9			0
80	5.2			0
90	5.5			0
95	5.7	0.02	0-1	0
100	5.9			0
110	6.3			0
120	6.8			0
130	7.7	Neg	0-1	0
140	8.8			0
150	10.4			0
160	12.5			0
170	17.0			0
174	20.0	0.01	3-5	0
180	25.1			0
188	40.0	0.05	6-8	0
190	36.0			

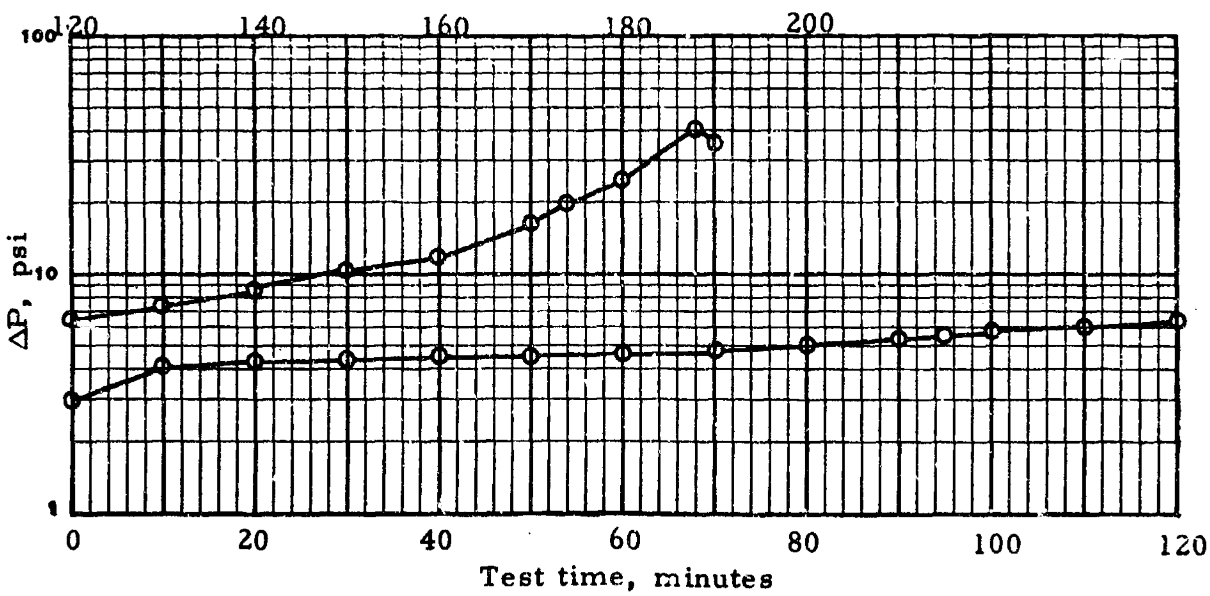


TABLE 7. LOOP TEST NO. 52 Date: 22 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4203, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.

( ) Fresh-fuel blend OR (x) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08136119	0.15	vol. %
Corrosion inhibitor Santolene C, Lot NH04-006	4	lb/Mbbl

Fuel inlet temperature, °F	75 ± 1	Fuel throughput, gal	2747
Test duration, min	137	Avg. flow rate, gpm	20.0

Actual element weight gain, g	349
Calculated dirt loading, g	430

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.83	0.60	0.08
	WSIM, dist. water	9.1		--
	WSIM, inj. water	85		79
	IFT, dist. water, dyn/cm	35.2		--
	IFT, inj. water, dyn/cm	18.5		22.9
	FSII content, vol. %	0.14		0.03
Injection water	Solids, mg/liter		0.1	--
	pH		8.2	8.1
	ST, dyn/cm		69.5	69.8
Coalesced water	pH		8.2	8.2
	ST, dyn/cm		35.8	53.5
	FSII content, vol. %		4.6	2.1

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	2	2	2	1	1		1
Cleanup ΔP, psi	0	0	0	0	0		0
Throughput, gal	306	913	1521	2212	2889		3053

TABLE 7. LOOP TEST NO. 52 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.0			0
10	3.8			0
20	4.1			0
30	4.2	0.04	2-4	0
40	4.1			0
50	4.1			0
60	4.1			0
70	4.2			0
80	4.5			0
90	5.2			0
95	6.0	0.03	0-1	0
100	7.5			0
110	11.2			0
120	17.3			0
122	20.0	0.00	0-1	0
130	31.0	0.07	0-1	0
135	40.0	Neg	0-1	0
137	29.3			0

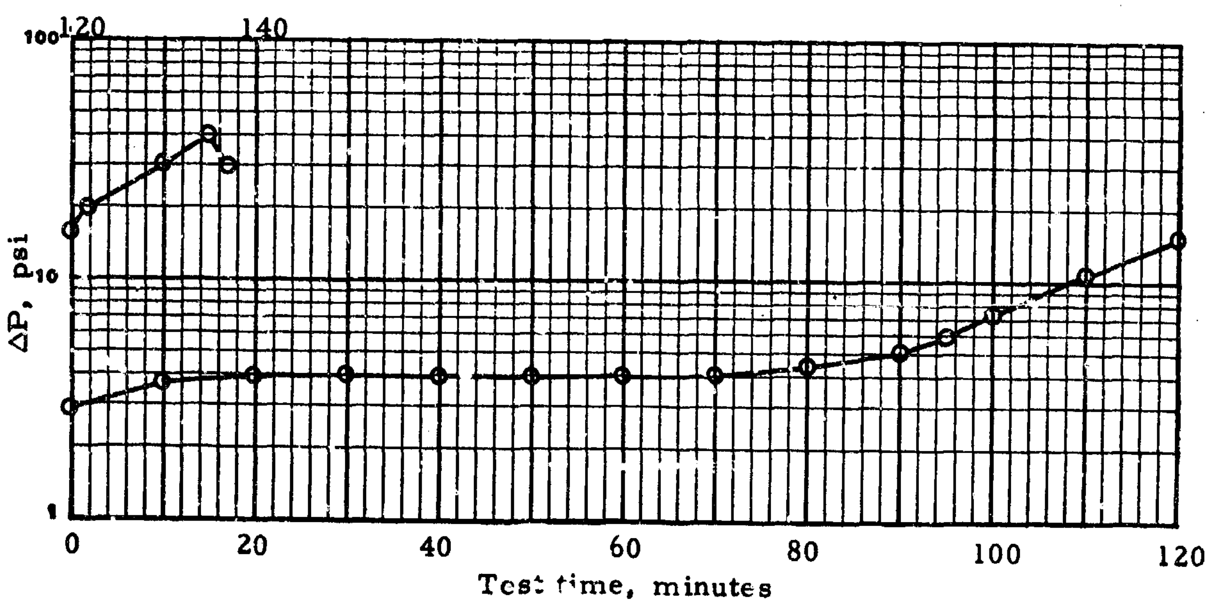


TABLE 8. LOOP TEST NO. 53 Date: 23 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
( ) Fresh-fuel blend OR (x) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor, Santolene C, Lot NH04-006	4	lb/Mbbl

Fuel inlet temperature, °F	75 ± 1	Fuel throughput, gal	2911
Test duration, min	146	Avg. flow rate, gpm	19.9

Actual element weight gain, g	399
Calculated dirt loading, g	481

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.09	0.04	0.15
	WSIM, dist. water	95		--
	WSIM, inj. water	75		68
	IFT, dist. water, dyn/cm	35.8		--
	IFT, inj. water, dyn/cm	25.1		28.2
	FSII content, vol. %	0.15		0.02
Injection water	Solids, mg/liter		0.0	--
	pH		8.0	8.0
	ST, dyn/cm		70.3	70.2
Coalesced water	pH		8.2	8.2
	ST, dyn/cm		56.4	56.8
	FSII content, vol. %		5.9	1.7

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	3	3	3	3	3		3
Cleanup ΔP, psi	0	0	0	0	0		0
Throughput, gal	306	898	1500	2199	2898		3217

TABLE 8. LOOP TEST NO. 53 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	2.8			0
10	3.7			0
20	3.7			0
30	3.8	0.03	0-1	0
40	4.0			0
50	4.0			0
60	4.1			0
70	4.2			0
80	4.5			0
90	5.0			0
95	5.4	0.07	5-7	0
100	6.4			0
110	8.9			0
120	11.6			0
130	18.2	0.12	4-5	0
132	20.0	0.10	4-5	0
140	32.3			0
144	40.0	0.05	8-10	0
146	33.0			0

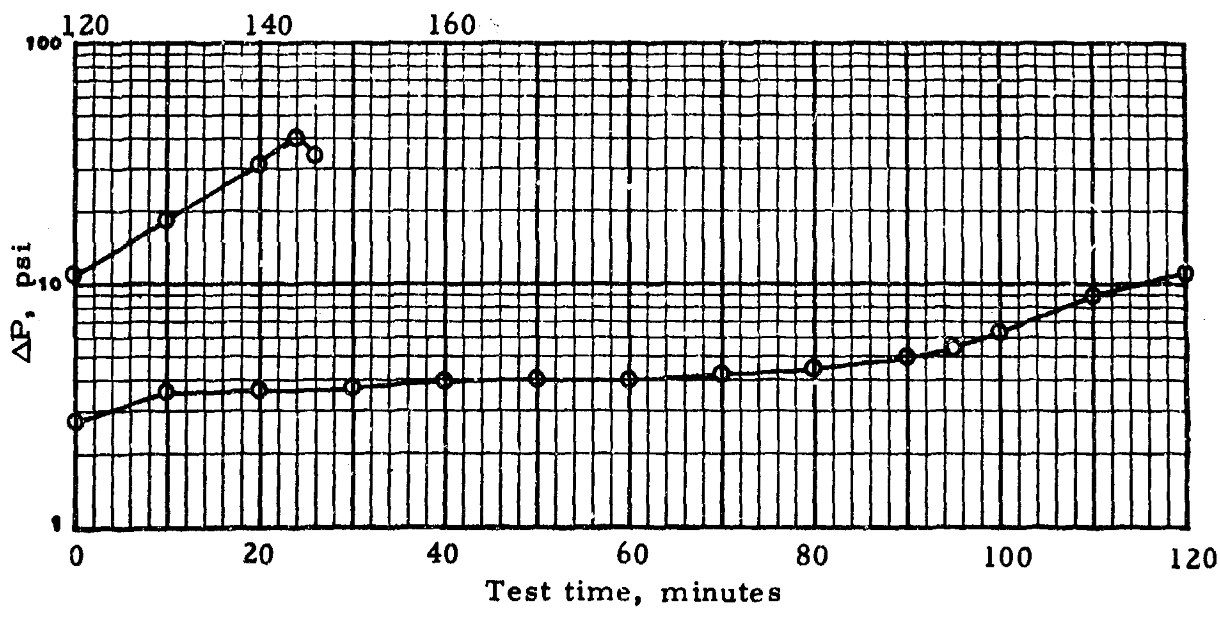


TABLE 9. LOOP TFST NO. 54 Date: 24 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
( ) Fresh-fuel blend OR (x) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor, Santolene C, Lot NH04-006	16	lb/Mbbl

Fuel inlet temperature, °F	75 ± 2	Fuel throughput, gal	1960
Test duration, min	99	Avg. flow rate, gpm	19.8

Actual element weight gain, g	235
Calculated dirt loading, g	235

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.01	0.25	0.03
	WSIM, dist. water	80		--
	WSIM, inj. water	88		75
	IFT, dist. water, dyn/cm	32.1		--
	IFT, inj. water, dyn/cm	11.9		12.7
	FSII content, vol. %	0.12		0.02
Injection water	Solids, mg/liter		0.2	--
	pH		8.0	8.0
	ST, dyn/cm		70.1	70.0
Coalesced water	pH		8.0	8.0
	ST, dyn/cm		54.0	54.8
	FSII content, vol. %		5.7	1.6

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	1	1	1	1			1
Cleanup ΔP, psi	0	0	0	0			0
Throughput, gal	366	962	1558	2238			2326

TABLE 9. LOOP TEST NO. 54 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.3			0
10	3.8			0
20	3.9			0
30	4.0	Neg	6-8	0
40	4.1			0
50	4.0			0
55	4.0			0
	(a)			
60	4.0			0
70	4.5			0
80	7.1			0
88	20.0	0.04	8-9	0
90	27.0			0
94	40.0	0.04	8-9	0
96	45.0			0
99	38.0			0

(a) Solids injection started at 55 min, i.e., 5 min before regular time.

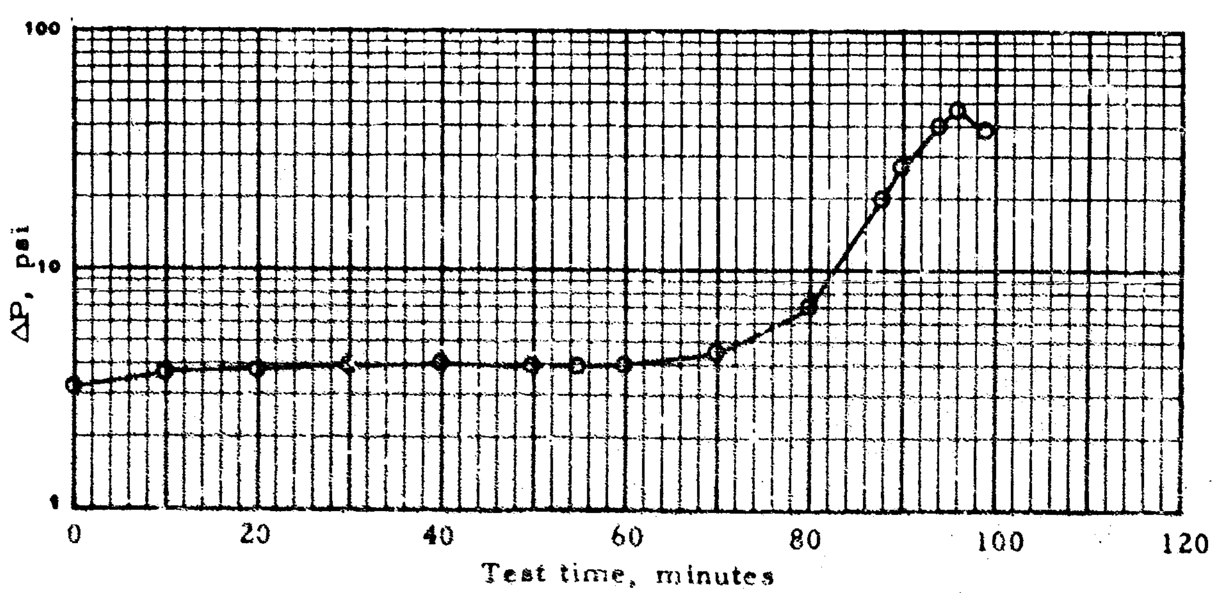


TABLE 10. LOOP TEST NO. 55 Date: 27 March 1967

Al/SS loop with 3" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
( ) Fresh-fuel blend OR (x) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor, Santolene C, Lot NH04-006	16	lb/Mbbl

Fuel inlet temperature, °F	75 ± 2	Fuel throughput, gal	2429
Test duration, min	122	Avg. flow rate, gpm	19.9

Actual element weight gain, g	335
Calculated dirt loading, g	338

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.07	0.06	0.01
	WSIM, dist. water	72		--
	WSIM, inj. water	74		75
	IFT, dist. water, dyn/cm	28.5		--
	IFT, inj. water, dyn/cm	14.1		16.1
	FSII content, vol. %	0.12		0.01
Injection water	Solids, mg/liter		0.2	--
	pH		8.1	8.0
	ST, dyn/cm		65.6	63.3
Coalesced water	pH		8.1	8.0
	ST, dyn/cm		53.0	53.4
	FSII content, vol. %		3.0	1.0

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	1	1	1	1			1
Cleanup ΔP, psi	0	0	0	0			0
Throughput, gal	302	904	1498	2200			2732

TABLE 10. LOOP TEST NO. 55 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.7			0
10	4.4			0
20	4.7			0
30	4.6	0.04	0-2	0
40	4.5			0
50	4.5			0
60	4.5			0
70	4.7			0
80	5.1			0
90	5.6			0
95	6.3	0.02	1-3	0
100	8.9			0
110	17.5			0
111	20.0	0.07	2-4	0
118	40.0	0.04	4-6	0
122	35.0			0

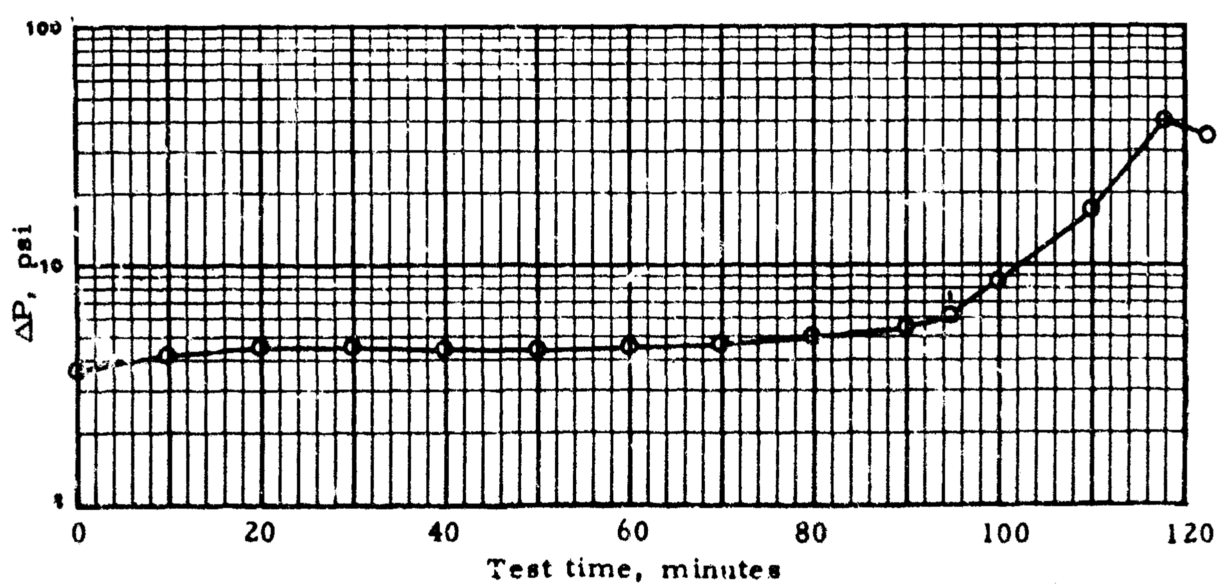


TABLE 11. LOOP TEST NO. 56 Date: 28 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
(x) Fresh-fuel blend OR ( ) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor, AFA-1, Lot 37	4	lb/Mbbl

Fuel inlet temperature, °F	75 ± 2	Fuel throughput, gal	3714
Test duration, min	186	Avg. flow rate, gpm	20.0

Actual element weight gain, g	622
Calculated dirt loading, g	709

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.10	0.02	0.01
	WSIM, dist. water	94		--
	WSIM, inj. water	86		84
	IFT, dist. water, dyn/cm	21.2		--
	IFT, inj. water, dyn/cm	18.8		21.6
	FSII content, vol. %	0.16		0.02
Injection water	Solids, mg/liter		0.1	--
	pH		8.0	8.1
	ST, dyn/cm		63.8	67.9
Coalesced water	pH		7.6	7.9
	ST, dyn/cm		38.6	41.0
	FSII content, vol. %		5.5	1.4

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	2	3	3	3	3	3	3
Cleanup ΔP, psi	0	0	0	0	0	0	0
Throughput, gal	306	864	1501	2199	2901	3499	4020

TABLE 11. LOOP TEST NO. 56 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.2			0
10	4.0			0
20	4.4			0
30	4.5	0.02	2-4	0
40	5.1			0
50	5.6			0
60	5.7			0
70	5.1			0
80	5.6			0
90	6.2			0
95	6.6	0.04	2-4	0
100	7.1			0
110	8.2			0
120	9.5			0
130	11.0	0.05	7-9	0
140	12.3			0
150	14.7			0
160	18.5			0
162	20.0	0.07	10-12	0
170	25.0			0
180	35.0			0
184	40.0	0.02	12-14	0
186	36.0			0

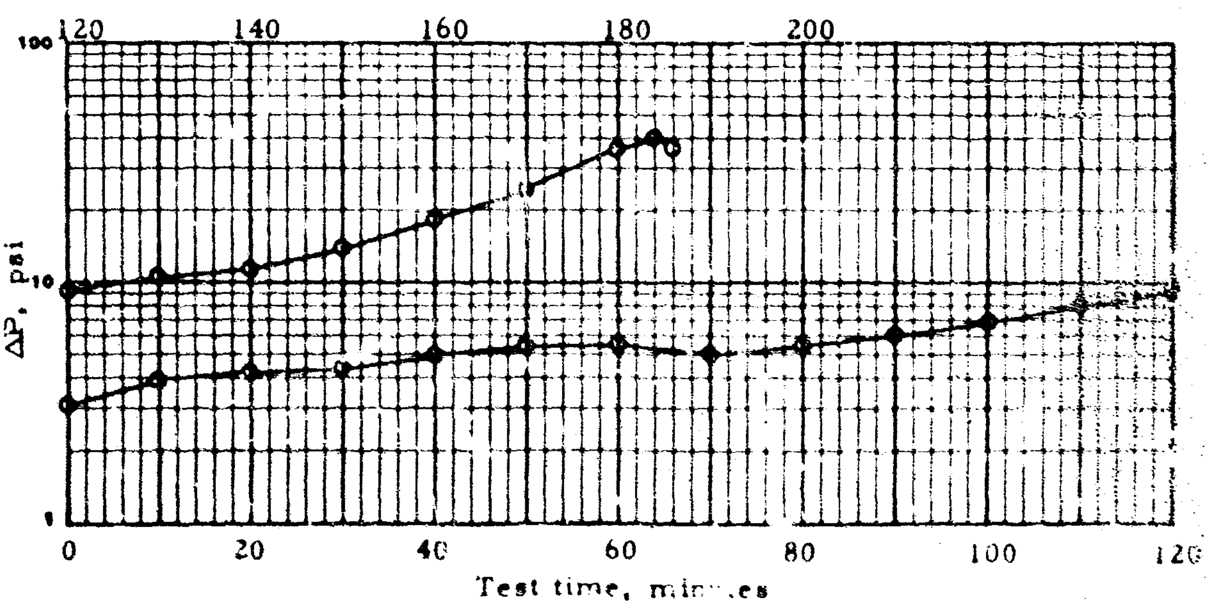


TABLE 12. LOOP TEST NO. 57 Date: 30 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
(x) Fresh-fuel blend OR ( ) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor, Tolad 244, Lot 47-12	5.5	lb/Mbbl

Fuel inlet temperature, °F	75	Fuel throughput, gal	84
Test duration, min	4[a]	Avg. flow rate, gpm	21

Actual element weight gain, g
Calculated dirt loading, g

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter			
	WSIM, dist. water			
	WSIM, inj. water			
	IFT, dist. water, dyn/cm			
	IFT, inj. water, dyn/cm			
	FSII content, vol. %		(a)	
Injection water	Solids, mg/liter			
	pH			
	ST, dyn/cm			
Coalesced water	pH			
	ST, dyn/cm			
	FSII content, vol. %			

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	2						2
Cleanup ΔP, psi	0						0
Throughput, gal	84						84

(a) Test terminated after 4 min of pre-test time because of excessive pressure drop. No water or solid contaminant was injected.

TABLE 12. LOOP TEST NO. 57 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
(Pre-test)				
0				
4	45.0			

Test terminated after 4 min of pre-test period with fuel flow only.

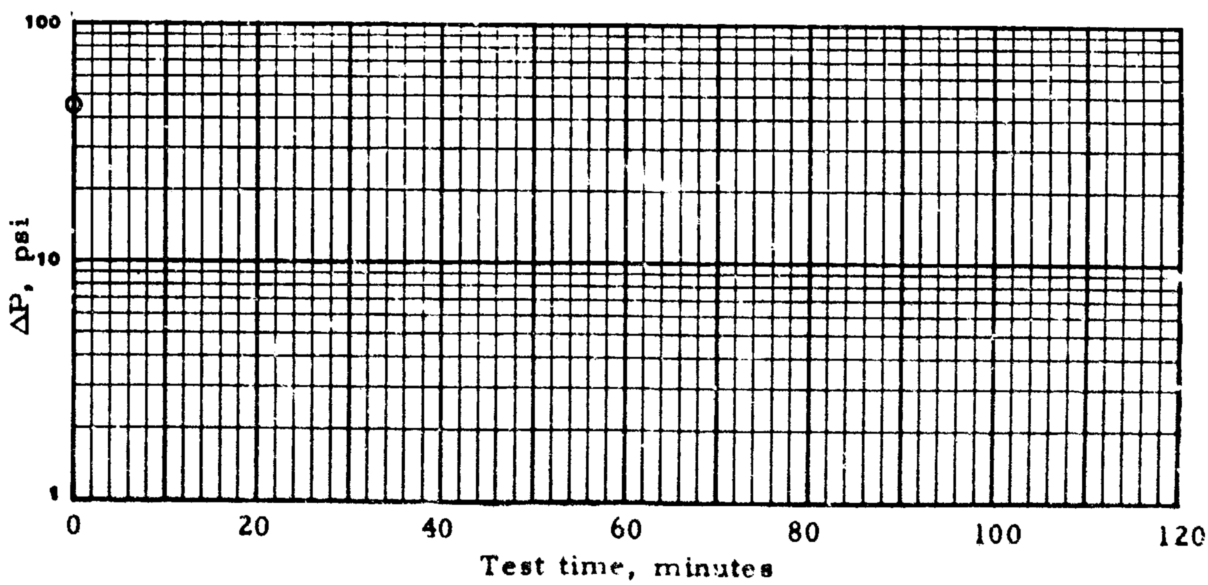


TABLE 13. LOOP TEST NO. 58 Date: 30 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
(x) Fresh-fuel blend[a] OR ( ) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor, Tolad 244, Lot 47-12	5.5	lb/Mbbl

Fuel inlet temperature, °F	75 ± 3	Fuel throughput, gal	2909
Test duration, min	147	Avg. flow rate, gpm	19.8

Actual element weight gain, g	448
Calculated dirt loading, g	480

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.10	0.11	0.04
	WSIM, dist. water	88		--
	WSIM, inj. water	74		35
	IFT, dist. water, dyn/cm	27.6		--
	IFT, inj. water, dyn/cm	14.0		15.1
	FSII content, vol. %	0.12		0.01
Injection water	Solids, mg/liter		0.2	--
	pH		8.1	8.1
	ST, dyn/cm		69.9	71.8
Coalesced water	pH		7.9	8.0
	ST, dyn/cm		45.0	48.5
	FSII content, vol. %		5.6	1.4

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	2	2	2	2	1		2
Cleanup ΔP, psi	0	0	0	0	0		0
Throughput, gal	321	902	1499	2202	2870		3230

(a) Fuel blend, which had been used in aborted test (No. 57) without any water or solids injection, is still considered "fresh."

TABLE 13. LOOP TEST NO. 58 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.1			0
10	3.8			0
20	3.9			0
30	4.1	0.07	4-6	0
40	4.2			0
50	4.1			0
60	4.1			0
70	4.4			1
80	5.0			2
90	5.1			2
95	6.9	0.10	6-8	2
100	8.0			1
110	10.2			1
120	13.8			2
128	20.0	0.12	12-14	2
140	32.5			2
144	40.0	0.08	10-12	2
147				0

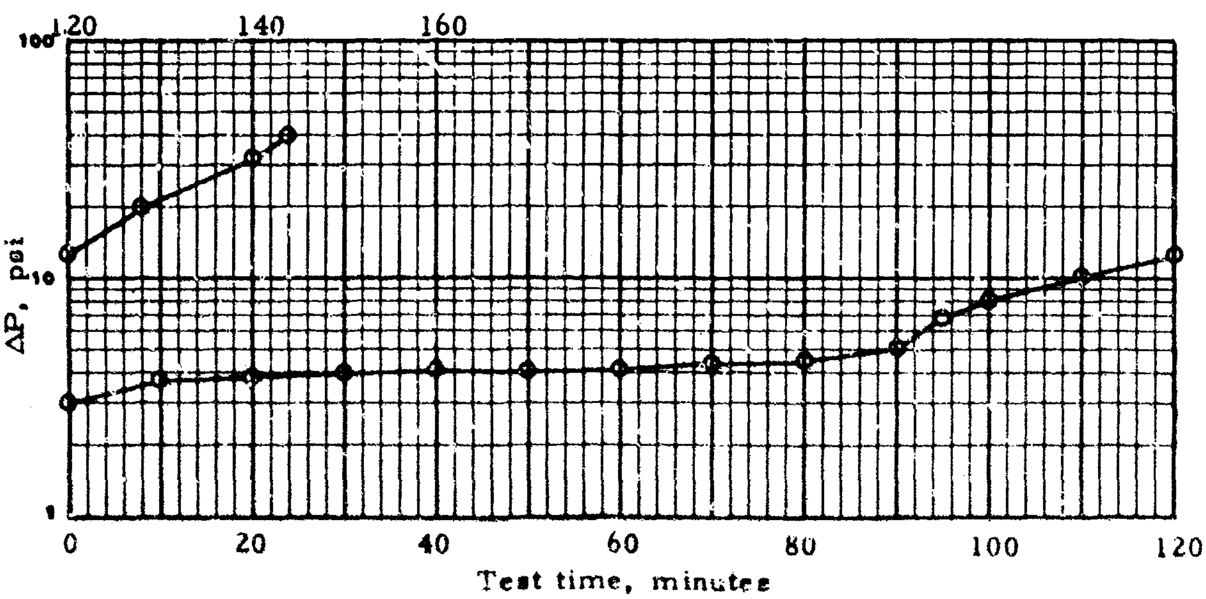


TABLE 14. LOOP TEST NO. 59 Date: 31 March 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.

(x) Fresh-fuel blend OR ( ) Fuel from previous test		
Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor, Lubrizol 541, Lot 24794	5	lb/Mbbl

Fuel inlet temperature, °F	75 ± 2	Fuel throughput, gal	3294
Test duration, min	164	Avg. flow rate, gpm	20.1

Actual element weight gain, g	578
Calculated dirt loading, g	589

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.11	0.05	0.09
	WSIM, dist. water	--		--
	WSIM, inj. water	83		88
	IFT, dist. water, dyn/cm	31.4		--
	IFT, inj. water, dyn/cm	25.1		26.8
	FSII content, vol. %	0.14		0.02
Injection water	Solids, mg/liter		0.0	--
	pH		8.0	8.0
	ST, dyn/cm		70.7	71.1
Coalesced water	pH		7.6	7.9
	ST, dyn/cm		55.4	51.5
	FSII content, vol. %		(a)	1.40

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	2	0	0	0	0	0	0
Cleanup ΔP, psi	0	0	0	0	0	0	0
Throughput, gal	324	918	1521	2220	2915	3510	3618

(a) Sample too cloudy to analyze.

TABLE 14. LOOP TEST NO. 59 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	3.6			0
10	--			0
20	5.5			0
30	5.5	0.04	3-5	1
40	5.5			0
50	5.8			0
60	5.8			0
70	6.2			0
80	7.0			0
90	7.8			0
95	8.0	0.25	2-4	0
100	8.8			0
110	10.0			0
120	12.5			0
130	15.0	0.06	2-4	0
140	18.6			0
143	20.0	0.18	2-4	0
150	25.6			0
160	35.5			0
163	40.0	0.33	0	0
164	34.5			0

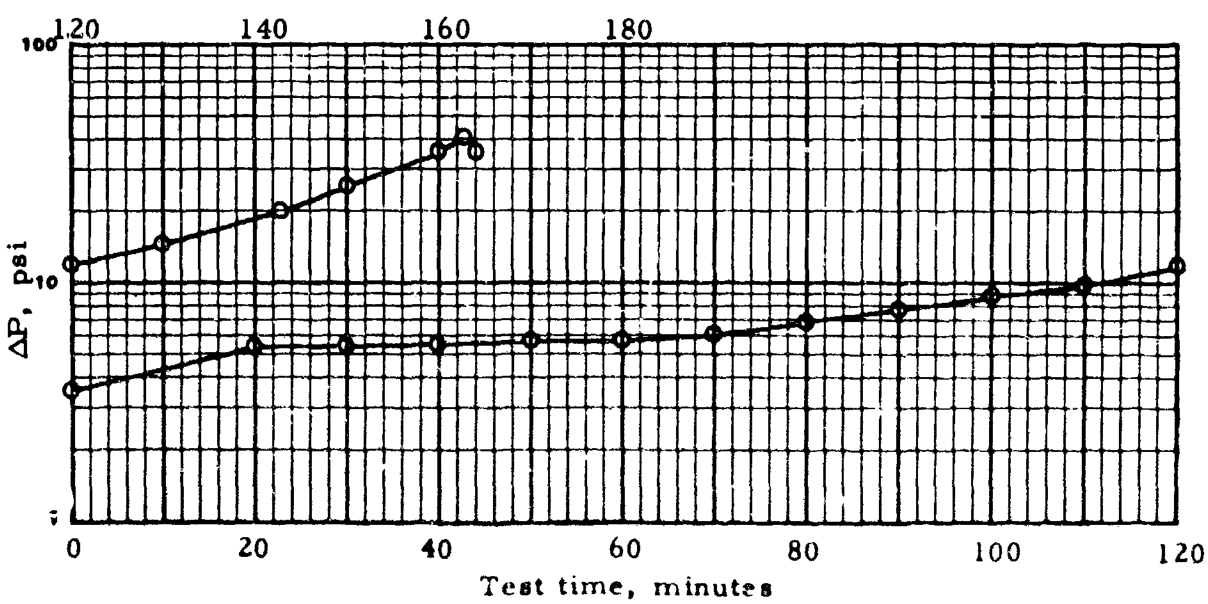


TABLE 15. LOOP TEST NO. 60 Date: 3 April 1967

Al/SS loop with 8" I.D. aluminum housing, military-standard double-wall canister, and military-standard element (Filters Inc. I-4208, Lot 286).

Procedure 10: Modified MIL-F-8901A inhibited-fuel test with fuel flow 20 gpm and inlet pressure 70 psig. Type B synthetic water injected at 0.2 gpm throughout test, coarse AC dust at 5.72 g/min after 60 min.

Test fuel uninhibited JP-4 Batch 14 plus additives as shown.
(x) Fresh-fuel blend OR ( ) Fuel from previous test

Fuel system icing inhibitor, Dow, Lot 08186119	0.15	vol. %
Corrosion inhibitor	None	lb/Mbbl

Fuel inlet temperature, °F	75 ± 2	Fuel throughput, gal	2772
Test duration, min	138	Avg. flow rate, gpm	20.1

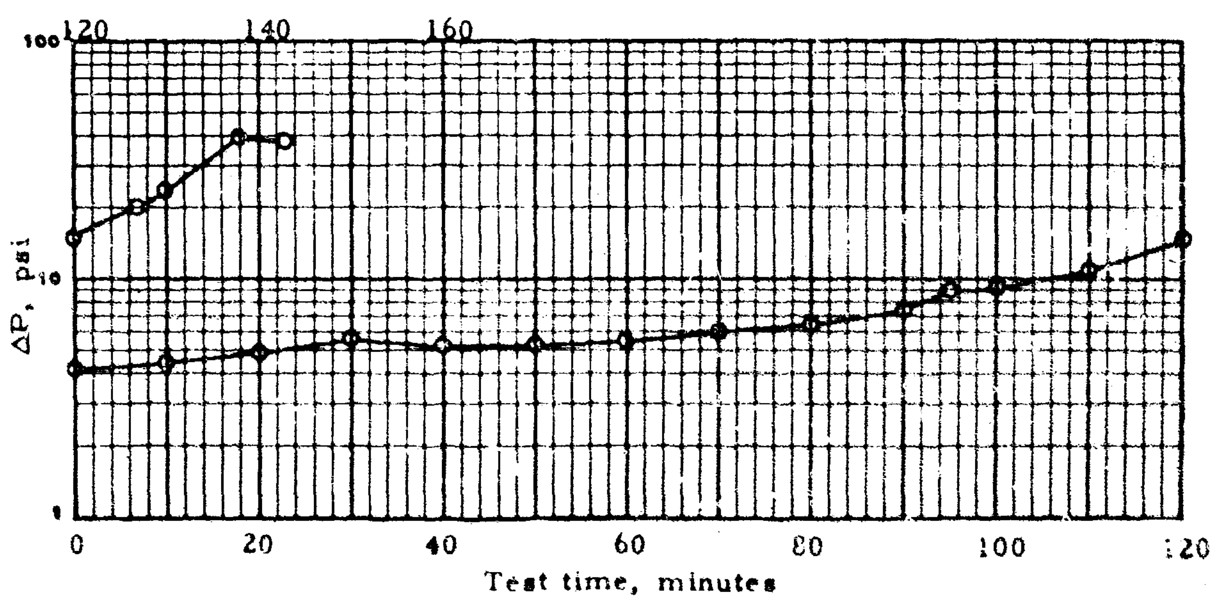
Actual element weight gain, g	414
Calculated dirt loading, g	446

		Pre-test	30 min	95 min
Influent fuel	Solids, mg/liter	0.12	0.04	0.01
	WSIM, dist. water	83		--
	WSIM, inj. water	90		96
	IFT, dist. water, dyn/cm	42.5		--
	IFT, inj. water, dyn/cm	40.8		42.2
	FSII content, vol. %	0.15		0.01
Injection water	Solids, mg/liter		0.2	--
	pH		7.9	7.9
	ST, dyn/cm		73.2	72.4
Coalesced water	pH		8.0	8.0
	ST, dyn/cm		63.9	69.2
	FSII content, vol. %		4.1	1.2

Time, min:	Pre-test	30	60	95	130	160	End
Screen ΔP, psi	2	2	2	1	0		2
Cleanup ΔP, psi	No readings; gages inoperative.						
Throughput, gal	332	929	1527	2239	2907		3104

TABLE 15. LOOP TEST NO. 60 (Cont'd)

Time, min	ΔP, psi	Effluent Fuel Quality: Solids, mg/liter	Free Water, mg/liter	Totamitor Reading
0	4.3			0
10	4.6			0
20	5.0			0
30	5.7	0.03	1-2	0
40	5.3			0
50	5.3			0
60	5.5			0
70	6.0			0
80	6.5			0
90	7.5			0
95	9.0	Neg	0-1	0
100	9.2			0
110	11.5			0
120	15.0			0
127	20.0	0.02	0-1	0
130	23.6			0
138	40.0	Neg	1-2	0
143	39.0			0



APPENDIX B

DETAILED DESIGN INFORMATION

APPENDIX B

DETAILED DESIGN INFORMATION*

Components not covered in this Appendix are listed for identification in the Detailed Parts List (Appendix D), including manufacturer's part numbers, SwRI drawing numbers, and other information as applicable. Certain design information is also listed in the text of this report (Section II).

Totalizing Flowmeter (1-4)

A Rockwell-Brodie totalizing flowmeter, Model B-40C-AL, already on hand, was modified by the manufacturer to conform to material requirements for the Al/SS loop. This flowmeter is installed in the fuel pump discharge line to record the total fuel throughput and to check average flow rates. Fuel flowing through the meter turns a pair of heat-treated aluminum helical rotors geared to a mechanical counter. The counter registers 0-9999 gal and is equipped with a zero-start lever to clear the counter. Even though the operating principal is simple, a large number of parts are required between the fuel input and the totalized output. The manufacturer's modifications consisted of replacing copper-alloy and steel parts with more suitable materials. All fuel-wetted parts are now either aluminum or austenitic stainless steel except the following: rotor ball bearings - 440 C stainless steel; main rotor shafts - Nitralloy; miscellaneous small parts - 416 and 450 stainless steels, with one joint made with grade 45 "Easy Flow" silver solder. This silver solder represents the only use of any high-copper alloy in the entire fuel system of the Al/SS loop. The manufacturer states that it would not be practical to replace this part with a welded unit.

The meter required special adaptor flanges to connect to the 2-in. fuel line. A 5-in.-dia, 1-in.-thick aluminum disk was bored and welded to a 2 X 1-1/2-in. concentric reducer. The round aluminum flange is bolted to the meter with four 1/2-in. bolts on a 3-11/16-in.-diameter bolt circle.

Heat Exchanger (1-5)

This is a two-pass stainless steel (Type 316) shell-and-tube unit with fixed tube bundle. PTFE-impregnated asbestos full-face gaskets are used between the end bonnets and the shell-and-tube assembly. The fuel passes through the tube side, and water and steam pass through the shell side in a baffled path. Maximum working pressures for the shell and tube sides are 300 psi and 150 psi, respectively. Maximum working temperature is 400 °F.

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*Component numbers refer to the Detailed Parts List (Appendix D).

Tube size is 3/8-in. OD, and the effective tube area is 26.4 ft^2. Threaded pipe connections are used for the fuel and water/steam lines. The unit is equipped with drain plugs.

Design calculations were based on the manufacturer's values for heat transfer coefficient and on a cooling water temperature of 62°F, typical of summertime conditions for this particular water distribution system. Total heat inputs by the fuel pump were calculated by assuming complete conversion of drive power to heat in a closed, recirculating fuel system. Such calculations were made for the normal operating condition, with the 8-in. pump impeller delivering fuel at 20 gpm and 105 psig, and for the maximum operating condition, with the 9-5/8-in. pump impeller delivering fuel at 60 gpm and 145 psig. In each case, a fuel supply initially at 90°F was assumed.

The calculations indicated that, at the maximum operating condition, the heat exchanger would remove all the pumping heat and cool the fuel from 90 to 88°F. Thus, with a cooling effect of only 2°F per pass, the exchanger is at best marginal for the maximum condition. Prolonged recirculation would be necessary to reduce the fuel temperature even to 80°F, since the cooling rate would drop off as the temperature differential between fuel and cooling water became smaller.

At the normal operating condition, the calculations indicated that the exchanger would remove all the pumping heat and cool the fuel to 80°F, i.e., provide a net cooling effect of 10°F per pass when starting with 90°F fuel. On this basis, the exchanger appeared to be more than adequate for use at flow rates on the order of 20 gpm. However, practical experience has indicated that net cooling rates are much slower than indicated by the calculations. In summertime operation, 80°F is the lowest fuel temperature that can be attained consistently; operating at 75°F fuel temperature is not feasible, even with prolonged recirculation in an attempt to cool the fuel supply. This does not appear to be any discrepancy in exchanger performance, but rather a greater heat input from the pump than was anticipated. This increased heat input may be a result of handling JP-5 fuel in later tests, since the higher viscosity of this fuel would be expected to result in greater consumption of power in internal fluid frictional heating. The curves for pump power requirements are based on pumping water, and the values obtained from the curves (and used in the temperature-rise calculations) are probably too low for application to JP-5 fuel.

When starting with cold fuel, steam is fed along with water into the exchanger. The exit line is wide open; i.e., no steam pressure is maintained within the shell of the exchanger. The exchanger performance in heating the

the fuel is more than adequate because of the large temperature differential between steam and fuel, and there is no need to pressurize the steam side to increase the efficiency. The steam supply is throttled manually, and the water supply cuts in automatically as the fuel reaches the control point.

The heat exchanger, with an effective surface of 26.2 ft^2, is reasonably satisfactory for 20-gpm flow conditions provided that the fuel temperature is to be held to no lower than 80°F. It is at best marginal for higher flow rates. In order to provide fully adequate single-pass cooling at high flow rates in the present system, about five times the present heat exchange surface would be required. It was not feasible to provide such an exchanger in the design of the present system because of limitations on delivery schedule. Future improvements in the temperature control system could be made either by providing a larger exchanger, by providing a more efficient pump, or both.

Temperature Controller (1-6)

Steam and water feed to the heat exchanger are regulated in order to control the temperature of the fuel supplied to the test section. The steam input is adjusted manually, and the water input is controlled by means of an automatic regulating valve actuated by a bellows-and-bulb assembly. The sensing element, a 30-in.-long stainless steel bulb, is installed in the 1-in. line ahead of the test section (downstream from the heat exchanger). The temperature controller has a range of 60 to 120°F. The regulator valve body is made of bronze with 1-1/2 NPT threaded connections. Spring tension is adjusted to change the temperature setting. The temperature regulator is provided with overheat protection.

Totamitors (1-7)

Two Bowser-Briggs Totamitors, Model No. 861A-LS-APV 2.5, are incorporated in the loop to monitor fuel cleanliness. One is installed in the influent fuel line prior to injection of water or solid contaminants. The other is installed in the effluent fuel line immediately after the test housing. Both units are installed vertically with fuel flowing upward, the preferred configuration for avoiding problems with entrained air bubbles. Each unit includes a light source and sensing cell, with a disk between them to block direct light transmission. Light reaches the sensing cell mainly by forward scattering, which is a function of the amount, dispersity, and optical properties of solid and liquid materials dispersed in the fuel. The Totamitors are installed in the main fuel flow line by means of special adaptors, APV No. 31-15F/SP, each consisting of a tapered reducer (2-1/2-to 1-1/2-in. OD sanitary-thread tube size) modified by welding a standard flange to the small end. The

Totamitor bodies and adaptors are stainless steel. The rated working pressure is 150 psig.

The sensing cell outputs are fed to remote-located amplifiers, meters, and fast-response recorders. These were transferred from other equipment, and complete identification data are not available.

Mixing Screen (1-8)

The mixing screen assembly is installed in the 1-in., high-velocity fuel flow section, immediately downstream from the water injection point. This screen serves to disperse the injected water, forming a fine suspension in the fuel. The mixing-screen unit was designed and fabricated by SwRI. The screen areas were chosen on the basis of previous experience with a basket strainer with 100-mesh screen that had been used successfully in another single-element test loop. The screen area of this strainer had been partially masked, leaving 2.24 in^2 of screen area for use in 20-gpm tests. This ratio, 0.112 in^2 per gpm fuel flow rate, corresponds to a superficial fuel velocity of 2.87 ft/sec at the screen. For the Al/SS loop, three screen areas were selected to cover the flow rate range of 15 to 60 gpm:

Screen designation	A	B	C
Screen area, in^2	2.2	3.6	5.6
Nominal flow rate, gpm	20	32	50

The ranges of applicability of these three screens and the maximum deviations of the superficial flow velocity (SFV) from the value of 2.87 ft/sec are as follows:

Screen:	A		B		C	
Flow rate, gpm:	15.0	24.4	24.4	39.2	39.2	60.0
SFV, ft/sec	2.19	3.56	2.18	3.49	2.25	3.44
Deviation, ft/sec	-0.68	+0.69	-0.69	+0.62	-0.62	+0.57
Deviation, %	-24	+24	-24	+22	-22	+20

A greater selection of screen areas would cover the design range of flow rates with smaller deviations in SFV. When the loop is operated for long periods at the same flow rate, it is desirable to have a mixing screen sized to give exactly 2.87 ft/sec SFV, and this has been the case in the Al/SS loop program, using Screen A at 20 gpm.

A similar calculation can be made on the basis of area ratios. The limits of applicability are shifted slightly, and it is found that the area ratio can be held between 0.086 and 0.147 in^2/gpm, i.e., within -23 and +31% of the nominal 0.112 in^2/gpm. However, the SFV criterion should be used for

design purposes, since it is related more directly to mixing energy than is the area ratio.

The mixing screen assembly is shown in Figure 12. This drawing illustrates the nearly identical support flanges that house the 100-mesh screens and the backup rings. The support flanges are held together with a Marman clamp that squeezes the elastomer seals on either side of the screen-ring to ensure that all the flow is directed through the screen. Since the pressure drop across the screen is relatively low, no reinforcement is needed at the outermost diameter of the screen, and the design is thereby simplified. The backup rings contain several wire spokes to prevent dishing of the screen in the event of pressure drop buildup due to screen plugging. The support flanges are stamped to mark the flow direction, in order to ensure proper installation. Also, the backup rings are indexed and the top side is indicated, so that they will always be installed with the segmented openings at the bottom. Such installation is extra insurance against trapping of particles in the assembly.

The screens are 100-mesh stainless steel plain-weave wire cloth, standard market grade, with 0.0045-in. wire diameter and 0.0055-in. openings. The open area is 30%.

In the early stages of design, it was anticipated that the pressure drop across a screen of limited area might be large enough to be troublesome. However, both prior experience and theoretical calculations led to the conclusion that, with the area ratios and velocities that are involved, the pressure drops would be small. The pressure drops may be calculated from the equation*

$$\Delta h = \left(\frac{n}{C^2}\right) \left(\frac{1-\alpha^2}{\alpha^2}\right) \left(\frac{V^2}{2g}\right)$$

where

Δh - head loss, ft
n - number of screens
C - screen discharge coefficient
α - fractional free projected area (here 0.30)
V - superficial velocity ahead of screen, ft/sec
g - 32.2 ft/sec^2

The screen discharge coefficient is about 1.0 for the flow conditions (Reynolds numbers) in the screen openings. At the nominal superficial flow velocity of

*Perry's Chemical Engineers Handbook, 4th Ed., Section 5, p. 35, 1963.

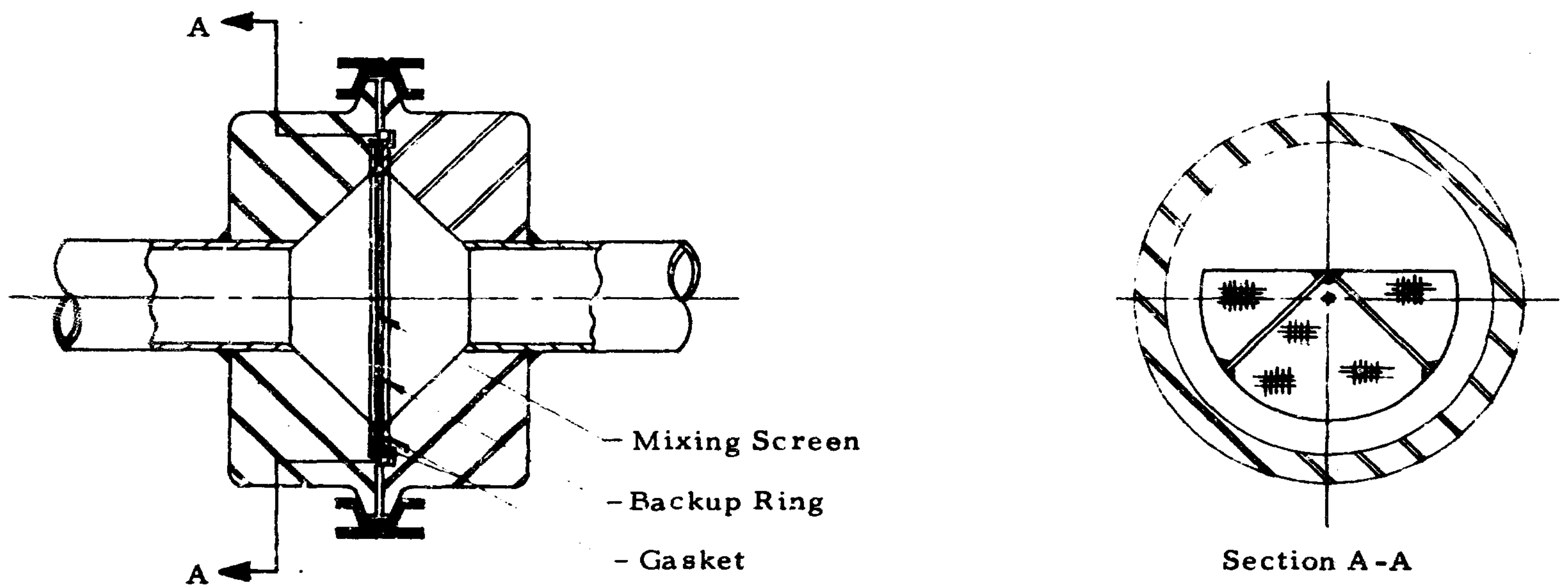

FIGURE 12. MIXING SCREEN ASSEMBLY

2.87 ft/sec, the head loss is only 1.3 ft or about 0.46 psi. At the maximum superficial flow velocity of 3.56 ft/sec (Screen A at 24.4 gpm), the head loss is 2.0 ft, or about 0.71 psi. The small pressure losses have since been confirmed by operating experience in the Al/SS loop.

The Reynolds number for the screen openings may be calculated as $DV\rho/\mu a$, where D is the width of the opening and V (as before) is the superficial velocity. For JP-5 fuel (z/s = 2 centistokes), the Reynolds numbers are 150 to 250 for the actual range of velocities with the three screens. Naturally, these low Reynolds numbers do not indicate streamline flow, since the flow is turbulent before and after the screen. However, the low Reynolds numbers do indicate that the screen's mixing function is not that of a turbulator. The screen probably serves mainly to break up any coarse water drops. The fine drops leaving the screen are further dispersed during passage of the mixture through the remainder of the 1-in. high-velocity flow section, where the flow regime is highly turbulent.

Single-Element Aluminum Test Housing (1-9)

This unit was fabricated prior to SwRI's assumption of facility operation, and no design details are available. It is not considered as an essential component of the Al/SS loop, since the loop is designed to accept any type of single- or multiple-element test unit up to the 60-gpm maximum flow rating. This housing was discussed in Section II and depicted schematically in Figure 8.

Single-Element Transparent Test Housing (1-13)

This unit was designed for use in the Al/SS loop but has seen little service. Design features and limitations were discussed in Section II, and the unit was depicted in Figure 9. SwRI drawing numbers are given in Appendix D.

Cleanup Filter-Separator (1-10)

This unit is a Bowser-Briggs Model 851-50, as modified by purchase specification and Bowser-Briggs Drawing No. PFSE 1570. The 16-in. OD aluminum housing (6061-T6 alloy) is equipped with four PTFE-coated screen canisters of the single-wall type and will accept four MIL-F-52308 elements. The unit is equipped with liquid-level sight gage, stainless steel air vent valve, and 2-in. 150-lb ASA flanges for inlet and outlet connections. The unit and accessories are of aluminum and stainless steel construction throughout. The top closure is a Victaulic-type coupling with Viton gasket. The unit is rated at 80 gpm and has a maximum working pressure of 75 psig.

Additive Injection System

The additive injection system consists of two subsystems. The corrosion inhibitor subsystem is designed for injection of small amounts of additive at slow rates. The fuel system icing inhibitor (FSII) subsystem is designed for injection of larger amounts of additive at faster rates. Both subsystems are designed to inject additives at rates corresponding to the final use concentration in the fuel so that they can be used for once-through line blending. These two subsystems together cover a wide range of injection rates, so that any pumpable fuel additive can be injected at the proper concentration.

Each subsystem is based on a purchased package-unit pump-drive combination. The corrosion inhibitor (small) subsystem uses a two-pump unit with variable-speed drive through a common pinion. Arrangement of these pumps for differential, single, or parallel output gives a very wide range of flow rates without changing drive gears or pinions. The FSII (large) subsystem uses a single pump with variable-speed drive. The entire system is located close to the additive injection point so as to keep the injection lines short.

The initial design criteria were based on injection of corrosion inhibitors, FSII, or dyes, the latter having been under investigation at the time the design was started. The following criteria were established:

Corrosion inhibitors - density 0.93 g/ml, max viscosity 400 cP
  Minimum injection 4 lb/1000 bbl at 15 gpm fuel flow = 41.84 ml/hr
  Maximum injection 20 lb/1000 bbl at 60 gpm fuel flow = 836.8 ml/hr
Dyes - density 1.0 g/ml, viscosity approx 50 cP
  Nominal injection 1 lb/1000 gal at 15 gpm fuel flow = 408.6 ml/hr
  at 60 gpm fuel flow = 1634 ml/hr

Fuel system icing inhibitor (FSII)* - density 0.96 g/ml, viscosity approx 1.6 cP
  Minimum injection 0.05% at 15 gpm fuel flow = 1,703 ml/hr
  Maximum injection 0.15% at 60 gpm fuel flow = 20,440 ml/hr

Total amounts of additives for a given blending operation were calculated on the basis of 600 gal of fuel (normal batch in a loop tank) and 15,000 gal of fuel (underground tank capacity):

Corrosion inhibitor,	4 lb/1000 bbl in 600 gal -	29 ml
	16 lb/1000 bbl in 15,000 gal -	3,486 ml

*Properties are those of 2-methoxyethanol, the major constituent (99.6%) of the FSII.

FSII,	0.05% in 600 gal -	1,136 ml
	0.15% in 15,000 gal -	85,162 ml

The corrosion inhibitor supply requirements were met by providing a 1-gal tank. The very small amount of inhibitor at the "minimum" condition (29 ml) illustrates the need for minimizing line size and length. The FSII supply would have to be about 22.5 gal at the "maximum" condition. However, the tank size was restricted to 6 gal for convenience. If operations ever required the maximum amount of FSII, refilling the tank would be no problem.

The additive injection system is shown schematically in Figure 5 (Section II). The two subsystems are entirely independent. Each has a separate injection line, leading to and welded into the fuel pump suction line.

The additive system is designed to meter and inject against pressures up to 125 psig. However, the pumps will not meter thin materials accurately against such pressures, particularly if the metering rate is low.

Corrosion Inhibitor Injection Subsystem

This subsystem consists of a 1-gal supply tank and two No. 1/2 Zenith Type B-4391 gear pumps with common drive pinion and variable-speed drive. The two pumps have different sized drive gears and therefore can be connected for differential delivery, with one pump drawing from the discharge of the other and returning fluid to the suction line of the first pump. With this arrangement, only the excess fluid (Pump A delivery minus Pump B delivery) is fed to the injection line. Very low flows can be metered accurately with this system. Pump A may be used alone by merely closing a valve. For higher metering rates, the two pumps may be used in parallel by modifying the plumbing.

The variable-speed drive can provide speeds from 10 to 400 rpm but is restricted to operation between 10 and 346 rpm, in order to limit pump speed to 250 rpm with the particular pinion and gear arrangement that is used. Formulas for the pump outputs are based on a displacement of 0.297 cc/rev for the pumps. Twenty-six teeth on the drive pinion, thirty-six teeth on the drive gear for Pump A, and forty-four teeth on the drive gear of Pump B. Delivery rates with this system (ml/hr) are as follows:

	N = 10 rpm	N = 346 rpm
$Q_A = 12.87\ N$	128.7	4455
$Q_B = 10.55\ N$	105.5	3645
$Q_{A-B} = 2.34\ N$ (differential)	23.4	810
$Q_{A+B} = 23.42\ N$ (parallel)	234.2	8100

Since the anticipated limits on required injection rates are 42 and 837 ml/hr, the differential-delivery arrangement will cover almost all situations, with Pump A alone for the higher end of this required range. Thus, no plumbing change is necessary to cover the entire range of required flow rates.

The corrosion inhibitor system lines are 1/8-in. tubing, which was chosen to minimize additive holdup, "travel time" from additive tank to injection point, and flushing requirements. This small tubing may place an upper limit on injection rates with viscous additives. However, for the maximum anticipated injection rate of 837 ml/hr with a 400-cP additive, the pressure drop through 0.10-in. ID tubing is only 4 psi/ft, or about 20 psi through the existing injection line. Higher injection rates (within the range of equipment capability) could cause problems; for example, at 8100 ml/hr, the same additive would require about 195 psi to overcome line resistance. So long as the additive is viscous, the pump will meter accurately against such pressures. Problems with viscous additives are more apt to show up in the pump suction line, and some replumbing may be necessary if very viscous additives are to be handled. The formula for pressure drop in streamline flow, given here for reference, is:

$$P = 1.2 \times 10^{-7} Qz/d^2$$

where

P - pressure drop, psi per foot of tubing
Q - flow rate, ml/hr
z - fluid viscosity, cP
d - tubing ID, in.

<u>Fuel System Icing Inhibitor (FSII) Injection Subsystem</u>

This subsystem consists of a 6-gal supply tank and a No. 3 Zenith Type B-4391 gear pump, driven by a variable-speed transmission. The drive speed is variable from 10 to 400 rpm, with stepdown to pump speeds of 6.2 to 248 rpm by means of a twenty-six-tooth drive pinion and forty-two-tooth pump drive gear. With a pump displacement of 1.752 ml/rev, the range of delivery rates is 651 to 26,100 ml/hr. Rates in the lowest end of this range may be difficult to maintain accurately because of the very slow drive rate and the possibility of fluid slippage, particularly if the pump is operating against any back pressure. Within the design requirements for FSII injection rates, 1,703 to 20,400 ml/hr, no problems are anticipated. The pump has been operated primarily at rates on the order of 13,600 ml/hr and has given very satisfactory service.

Although separate subsystems are provided for two different types of additives, it is often more convenient to use the large system for consecutive injection of both additives, rather than keeping the operations entirely separate.

As an example of such an operation, consider the blending of 600 gal of fuel with 0.15% FSII and 4 lb/1000 bbl of corrosion inhibitor, with a fuel flow rate of 40 gpm during the blending operation. First, the FSII (3400 ml) is injected at a rate of 13,600 ml/hr; this operation requires 15 min. Next, the required amount of corrosion inhibitor (26.04g) is cut with test fuel to a volume of 3400 ml, and this concentrate is put into the large additive supply tank and injected at the same rate as the anti-icing additive. This type of sequential blending has been used in practically all operations to date. However, the small system is available to provide for simultaneous injection of additives or to handle low-concentration additives that cannot be diluted with fuel conveniently.

Water Injection and Mixing System

The water system includes a pressure-booster system for supplying cooling water when the water-main pressure falls off, and a system for blending synthetic water contaminants and injecting either synthetic or natural water into the fuel line. The booster system was found to have very limited utility, since failures in water-main pressure were usually so severe that no water would feed to the booster pump. The booster system is of conventional design, with a surge tank "floating" on the line.

Design criteria for the water mixing and injection system are discussed in considerable detail in the text of this report (Section II). Some additional design information is presented here.

The water injection pump (Item 3-5 in Appendix D) is a screw-type positive-displacement pump with a chrome-plated stainless steel rotor turning in a natural rubber stator. The natural rubber was selected because of the necessity of handling aqueous solutions with high concentrations of FSII, which can damage Buna N and many other synthetic rubbers quite seriously. The selection of natural rubber was based on compatibility tests performed by the pump manufacturer. The pump drive speed is variable from 89 to 890 rpm. When driven at 450 rpm, the rated output against 70-psi back pressure is 3.1 gpm, i.e., well above the system design maximum of 1.8 gpm.

The three water rotameters (Item 3-7 in Appendix D) have the following ranges: 0.0015 to 0.02 gpm, 0.02 to 0.2 gpm, and 0.2 to 2.0 gpm. This covers the system design range of 0.0015 to 1.8 gpm without changing floats. It was originally intended to design the system for water injection rates of 0.0015 to 6.0 gpm. However, there were problems in obtaining a suitable pump and additional rotameter for the top end of this range. Also, it was virtually impossible to design a common piping system for this range of flow rates. For example, pipe or tubing of about 1/2-in. ID would be quite suitable for the high flow rate of 6 gpm, giving a pressure loss of about 0.5 psi/ft. At the low flow rate of 0.0015 gpm, flow velocity in a 1/2-in. line is only 0.15 ft/min; i.e., it would take some 6 to 7 minutes for the fluid to

traverse 1 foot of tubing. Under these conditions, several minutes of injection time could be "lost" before the water would reach the injection point.

The water system was shown schematically in Figure 6 (Section II). Lines and fittings in the tap-water supply line are ordinary materials (galvanized steel and brass) up to the prefilter. Lines and fittings beyond that point follow the same criteria as those established for the blending and injection system; i.e., the primary metal is stainless steel, and suitable plastics such as polyethylene are utilized wherever possible.

Lines from the injection pump to the rotameters and the return line from the pressure regulator to the supply tank are 3/8-in. tubing, either stainless steel or polyethylene. Lines from the rotameters to the water injection point, a relatively short distance, are 1/4-in. stainless steel tubing. Even with the 1/4-in. tubing, the travel time of fluid at the 0.0015-gpm injection rate is rather long, amounting to almost 2 minutes per foot of tubing. However, the rotameter inlets and outlets are manifolded, so that the lines up to the injection point can be purged and filled with fluid using one of the larger rotameters, after which the correct flow rate is established by means of the small rotameter.

Solid-Contaminant Mixing and Injection System

The design of this system was directed toward overcoming certain difficulties encountered in mixing, metering, and injecting solid contaminants into a pressurized fuel stream. Conventionally, in MIL-F-8901A testing, this is done by bypassing a portion of the main fuel stream through a hopper into which dry dirt is metered continuously; the mixture is then picked up by a slurry pump and injected back into the main fuel line. This method works reasonably well with high flow rates and high concentrations of solid contaminants. Dry dirt feeders are available for fairly accurate metering of dusts at the injection rates required for large units, e.g., about 0.2 to 0.4 lb/min in testing 600-gpm equipment under MIL-F-8901A. Under these conditions, the dirt feeder can be scale-mounted to provide a check on the amount of dirt injected. When testing smaller equipment or when injecting solid contaminants at very low concentrations, the metering problem becomes much more critical.

Preliminary design was based on four cases in which it was planned to meter premixed slurry into the fuel stream, rather than depend on a dry-dirt feeder for metering. Case A was designed to cover metering of a very dilute fuel-solids slurry to give a final concentration of 0.3 mg/liter of solids in the main fuel stream, so as to simulate the contamination level of relatively clean fuel encountered in the field. Cases B, C, and D were based on injection rates and amounts of solids that are required in MIL-F-8901A testing. These cases are defined more specifically as follows:

Case A - Dilute slurry of fine red iron oxide (RIO) in fuel; final concentration in fuel 0.3 mg/liter; running time 16 hr continuous.

Case B - RIO-fuel-water emulsion per MIL-F-8901A, consisting of 0.1 lb of RIO per lb of fuel-water mixture; emulsion injected at 0.0035-lb emulsion (0.000315-lb RIO)/gal of main fuel flow until element plugs; total RIO added at least 10-g/gpm fuel flow rate.

Case C - RIO per MIL-F-8901A; injected at 0.000315 lb/gal of main fuel flow until element plugs; total RIO added at least 10-g/gpm fuel flow rate.

Case D - Coarse AC dust per MIL-F-8901A; injected at 0.00063 lb/gal of main fuel flow until element plugs; total AC dust added at least 10-g/gpm fuel flow rate.

In order to cover these cases by injecting premixed materials, for the design range of 15 to 60-gpm fuel flow rate, the following limits are applicable:

Case:	A	B	C	D
Premix type:	Fuel-RIO	F/W-RIO	Fuel-RIO	Fuel-AC
Time, minutes	960	70+	70+	35+
Premix solids content, g/liter	1.64(a)	100(b)	43(a)	86(b)
Premix injection rate, ml/min	10.4-41.6	21.4-85.6	50-200	50-200
Total premix injected, liters	10.0-40.0	1.5-6.0+	3.5-14.0+	1.75-7.0+
Total solids injected, g	16.4-65.6	150-600+	150-600+	150-600+
Solids injection rate, g/min	0.0171-0.0684	2.14-8.56	2.14-8.56	4.28-17.12

(a) Assumed arbitrarily for design purposes.
(b) Based on assumed density 1.1 g/ml for premix.

To cover these cases, a 40-liter premix tank would be required (Case A). The required premix injection rates range from 10.4 ml/min (Case A) to 200 ml/min (Cases C and D).

The design evolved from these concepts without any substantial changes. The system was shown schematically in Figure 7 (Section II). The portion of the system including the rotameter, swirl hopper, dry dirt feeder, and injection pump is conventional and is typical of MIL-F-8901A testing systems. The slurry mixing tank and the slurry metering pump will handle the injection of the premix within the limits shown for the four cases.

The slurry mixing tank (Item 4-2) has a capacity of 15 gal, somewhat more than the 40-liter (10.6-gal) maximum capacity required under the four cases.

The slurry mixing pump (Item 4-3) serves solely to keep the slurry mixed, moving, and supplied to the metering pump. The mixing pump is a sealless unit in which a rotating eccentric presses a flexible Viton liner and moves the fluid by "squeegee" action. This pump is rated for 5-gpm delivery wide open, 1.7 gpm against 30 psig, and shutoff at 47 psig. The circulating lines were kept small (0.305-in. ID) to maintain high velocities. In these lines, the flow velocity corresponding to 1.7 gpm is 7.5 ft/sec. With thin slurry, having essentially the viscosity of jet fuel, the pressure drop in this line is 0.4 psi/ft. Since the line is relatively short, it appears that the pump will move thin slurry at a rate of at least 1.7 gpm. However, on thick materials such as red iron oxide emulsion, the pump is not adequate to maintain rapid circulation in this small line. In such cases, an air-driven stirrer is mounted on the mixing tank.

A simple tube-in-pipe heat exchanger (Item 4-4) is provided to cool the recirculating slurry. Assuming that all of the pump input power (1/4 hp maximum) shows up as heat in the recirculating system, the heat load on the exchanger is 636 Btu/hr. The heat exchanger has an effective area of 0.2 ft^2. Assuming a cooling water temperature of 65°F and a heat transfer coefficient of 50 Btu/hr/ft^2/°F, the equilibrium temperature attained by the fuel will be 129°F. In actual operation, the cooler is aided by natural convection losses from the equipment and lines, and, in any case, the assumption of complete conversion of maximum input power to heat is no doubt an overestimate for most operating conditions. If only 1/8 hp shows up as heat, then the equilibrium fuel temperature in the recirculating system is 97°F, which is more in line with actual experience.

In selecting the slurry metering pump, it was considered that no pump could be expected to meter slurries accurately against fuel-line pressure at the low injection rates required down to 10.4 ml/min. Therefore, the system was set up with the slurry metering pump discharging into an open swirl hopper, where the main injection pump picks up the mixture and injects it into the fuel line. This arrangement made it possible to select a peristaltic finger pump (Item 4-5) as the slurry metering pump. The capacity of this pump with 1/8-in. ID Viton tubing in the working section is adjustable from 0.5 up to 80 ml/min; with 1/4-in. tubing, delivery rates up to 250 ml/min can be obtained. Thus, this unit covers the necessary range of metering rates for the four cases outlined previously. However, it has never been tested thoroughly at very low metering rates with thin slurries. At the minimum metering rate of 10.4 ml/min (Case A), the flow velocity in 1/8-in. ID tubing is only 0.072 ft/sec or 4.7 ft/min, and it is anticipated that settling of solids in the tubing will be a considerable problem. Probably the only way to meter such small quantities of solids is to premix a much larger volume of more dilute slurry in order to increase the metering rates.

The conventional section of the solid-contaminant system includes a fuel supply line with rotameter (Item 4-1) with a range of 1.5 to 9 gpm. The required flow through the supply line, based on 15% of the total flow in the main loop, is 2.25 to 9.0 gpm. This line feeds fuel into a 15-gal swirl hopper (Item 4-7), where the dry dirt or premixed slurry is added. The fuel with added solids is picked up from the swirl hopper by the solid-contaminant injection pump (Item 4-8) and reinjected into the main fuel line. The injection pump is a screw-type positive-displacement pump with Buna N stator and chrome-plated stainless steel rotor. As discussed in the text (Section II), the pump manufacturer had found it impractical to use Viton-type rubber for stators because of difficulties in controlling dimensions during the curing process. The injection pump drive speed can be varied from 300 to 800 rpm. The rated deliveries against 70 p[illegible], corresponding to these speeds are 2.1 and 6.7 gpm, respectively. Thus, this pump will handle 15% of the total flow over the range of 15 to 45 gpm in the main loop, and 11% of the total flow at the maximum loop rate of 60 gpm. This 15% figure is by no means a firm or well-based criterion, and in fact is commonly regarded as a maximum. The only essential feature is that enough fuel be flowing through the swirl hopper to give good dispersal of the solids.

Some thought had been given to putting a level control on the swirl hopper, so that the fuel inflow rate would be regulated automatically, and only the injection pump rate would be adjusted manually. However, experience of SwRI and others had indicated that there was no particular difficulty in keeping the inflow and reinjection rates in step by manual adjustment of both. In view of this experience, and in view of certain practical difficulties in providing a suitable level control, this approach was abandoned.

As an alternate to the use of premixed slurries, dry dirt can be metered directly into the swirl hopper. Such metering could be applicable to Cases A, C, and D. Case A, however, would require extremely low metering rates for the dry red iron oxide, ranging from 17 to 68 mg/min; such rates are completely outside the capabilities of any known equipment. Some attempts were made to develop miniaturized equipment for micro-metering dry dirt, but no significant progress was made in this direction. For cases C and D, dry dirt feeding is practical, and in fact this is the method that has been used in almost all testing in the Al/SS loop. Dry-solid metering rates range from 2.14 to 17.12 g/min for the full range of test conditions. The dry-dirt feeder used for this purpose is an Omega Model 22-01 (Item 4-6). This unit feeds the solid material onto a rotating, grooved disk; the material in the groove is removed by a "plow" at the discharge side, where it falls into the fuel swirl hopper below. Feed rates are varied by controlling the disk rotational speed over a 100:1 range. For the various grooved disks that are available, the nominal ranges of feed rates are as follows:

Size AA	0.8 to 80 in^3/hr
Size A	1.2 to 120 in^3/hr

Size B	2.6 to 260 in^3/hr
Size C	5.5 to 550 in^3/hr
Size D	10.6 to 1060 in^3/hr

The feed rates required for the Al/SS loop are 2.14 to 17.12 g/min (Cases C and D). For a material having a bulk density of (for example) 70 lb/ft^3, the corresponding range of volumetric feed rates is 7 to 56 in^3/hr, indicating that the Size AA disk should be used under all conditions. With this disk, the groove is so small that feed rates tend to be uneven, especially at the low end of the range. Particular difficulty is experienced when the solid material has appreciable lumping tendencies. Feed rates tend to drift badly, even within a test period of an hour or two. Abrasive dusts give enough wear to be a serious maintenance problem. Finally, the small amounts of total feed (typically less than one pound per test) make it impossible to check total delivery or to monitor delivery rate accurately by scale-mounting the feeder. The type of platform scale that is required for this equipment is not sensitive enough for checking these small weight differences.

Although this type of dry-dirt feeder is not well adapted for the performance required here, it is apparently the best available. One other type of feeder, which uses vibration to move the solid material, was examined briefly for this purpose and found to be entirely unsuitable. The disk feeder has been used in practically all testing performed with the Al/SS loop. Calibration before every run and regular maintenance are required to achieve reasonably satisfactory results. In addition, it has become a regular practice to weigh the filter-separator test element before and after test to determine solids pickup as a rough check on the input of the dry-dirt feeder.

APPENDIX C

ARRANGEMENT AND CONFIGURATION OF COMPONENTS

APPENDIX C

ARRANGEMENT AND CONFIGURATION OF COMPONENTS

Main Fuel Loop

The overall layout of the main fuel loop is shown schematically in Figure 13. The relative positions of all major components are indicated, and the major components are identified by name and number. These identification numbers are also used for brevity and for positive identification of components in other figures and in the parts list in Appendix D. All sampling points, measuring points for pressure and temperature, and drain points for the main fuel loop are shown in Figure 13. Only the connection points for the additive, water, and solid-contaminant systems are shown; these systems will be discussed separately.

The Al/SS test loop is best described by tracing the path of the test fuel through the loop as in a typical test. Fuel enters the test loop, and the building, through the outside fuel connections. Generally, test fuel is brought into one of the two tanks before start of a test. During the test, fuel is drawn from the tank, circulating through the loop, and returned to the same tank. Examination of the arrangement of the entrance lines and associated valving will show that test fuel may be handled in several ways. Regardless of the routing of the incoming fuel in a test, the fuel must ultimately pass through the pump suction line and into the main fuel pump. In the pump suction line, corrosion inhibitor and fuel system icing inhibitor may be injected. This centrifugal pump, operating at 3500 rpm, provides thorough dispersal and blending of such materials. After leaving the main fuel pump, fuel flows in succession through the pressure regulator, totalizing flowmeter, heat exchanger, and influent Totamitor, and then into either the test line or the bypass line. During a test, fuel flows into the test line, coming first to a connecting line where a fraction of the main fuel flow can be diverted to the solid-contaminant system. (This diverted fuel, after picking up the solid contaminant, reenters the main fuel line downstream from the mixing screen.) The main fuel flow next passes the water injection point and then goes into the mixing screen, where the water is dispersed into very small droplets. After leaving the mixing screen, the fuel-water mixture receives the fuel from the solid-contaminant system and then enters the test section, where it passes through the single-element test housing and the effluent Totamitor. The fuel now either passes through or bypasses the cleanup filter-separator.

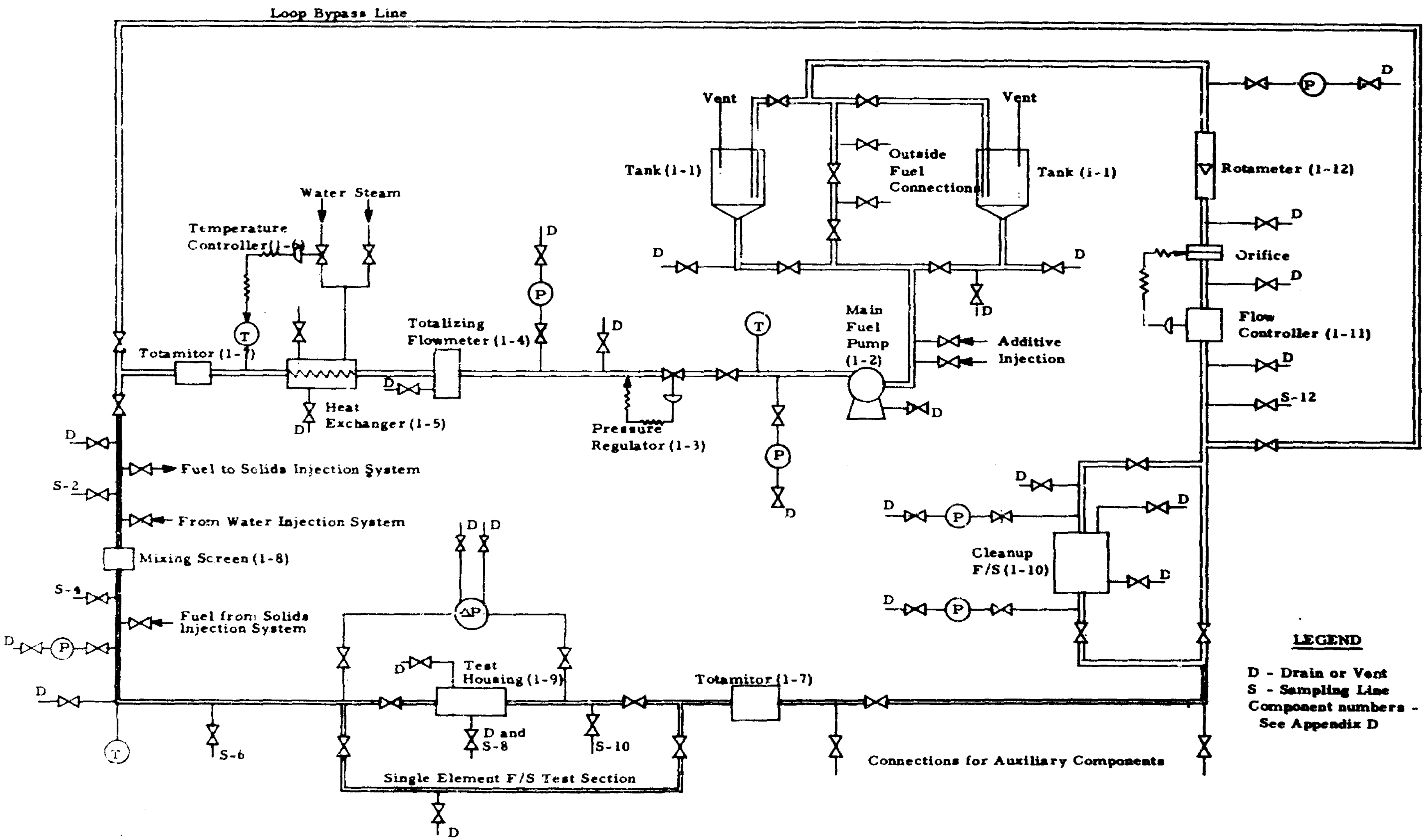

FIGURE 13. DETAILED SCHEMATIC DIAGRAM OF Al/SS LOOP

Once through or past the cleanup filter-separator, the fuel passes through the flow controller and associated downstream orifice and through a rotameter before going back to the tank or out of the building.

The physical layout of the Al/SS loop is shown by the photograph that is Figure 14. Clearly evident is the slope of the piping downward to the right; this facilitates complete draining of the loop. Components that are easily identified in this photograph are as follows: In the front center is the single-element aluminum test housing (1-9) with two of its viewing ports clearly visible; the fuel line exits from the upper part of the aluminum test housing and can then be traced on through the Totamitor (1-7) and thence to the cleanup filter-separator (1-10) at the right of the picture. Immediately behind the Totamitor is the additive injection system; its two Zenith pump systems are on the lower shelf of the table, and the two additive supply tanks are held in the table top. At the right and left background, the two 750-gal fuel tanks (1-1) are visible; between the fuel storage tanks is the test panel-board; in the left foreground is the solid-contaminant system.

Some of the main fuel loop components that cannot be seen clearly in Figure 14 will be shown in close-up photographs. In Figure 15, the main fuel pump (1-2), pressure regulator (1-3), totalizing flowmeter (1-4), and heat exchanger (1-5) are clearly visible, as are the connections between these components. The main fuel loop rotameter (1-12) and the water injection system booster pump (3-1) are also visible.

Additional details of the main fuel loop are shown in Figure 16. Here, the connections to the cleanup filter-separator (1-10) are shown, along with the bypass line, flow controller (1-11) and a sampling port (S-12).

Additive Metering and Injection System

The additive metering and injection system was shown schematically in Figure 5 (Section II). Criteria used in the design of this system are set forth in Appendix B. The actual arrangement of the components of this system is shown in the photograph that is Figure 17. The corrosion inhibitor supply tank (2-1) and the fuel system icing inhibitor supply tank (2-3) are contained in the table top, and directly below each tank is its associated metering pump or pumps. The additive injection point is in the suction line of the main fuel pump (1-2) to the left and rear of the additive metering and injection system.

Solid-Contaminant System

The solid-contaminant system was shown schematically in Figure 7 (Section II), and the actual arrangement of components is shown in the photograph that is Figure 18. In Figure 18, starting at the top, is the dry dirt feeder (4-6), directly beneath it the swirl hopper (4-7), and at the

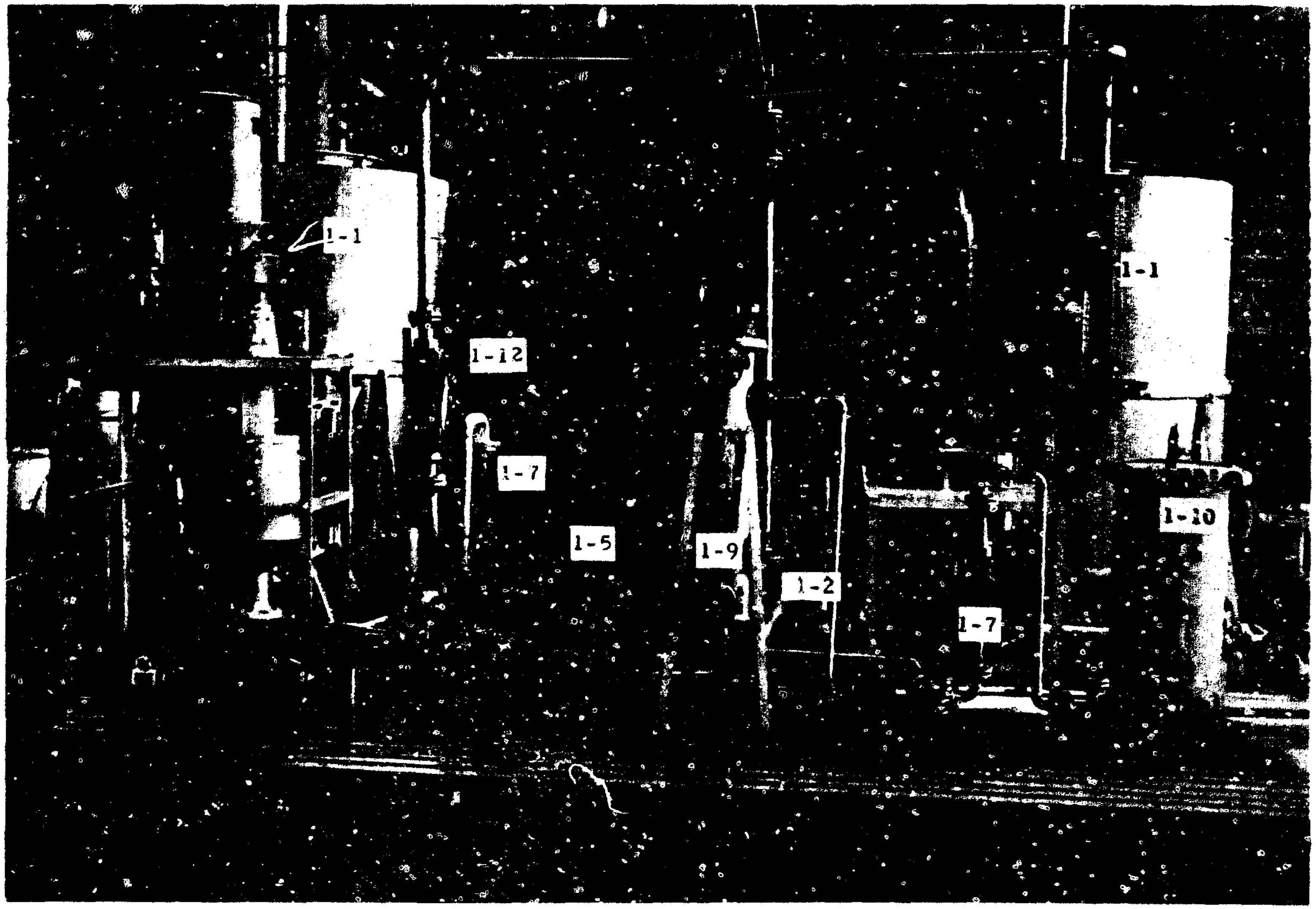

FIGURE 14. GENERAL ARRANGEMENT OF Al/SS LOOP

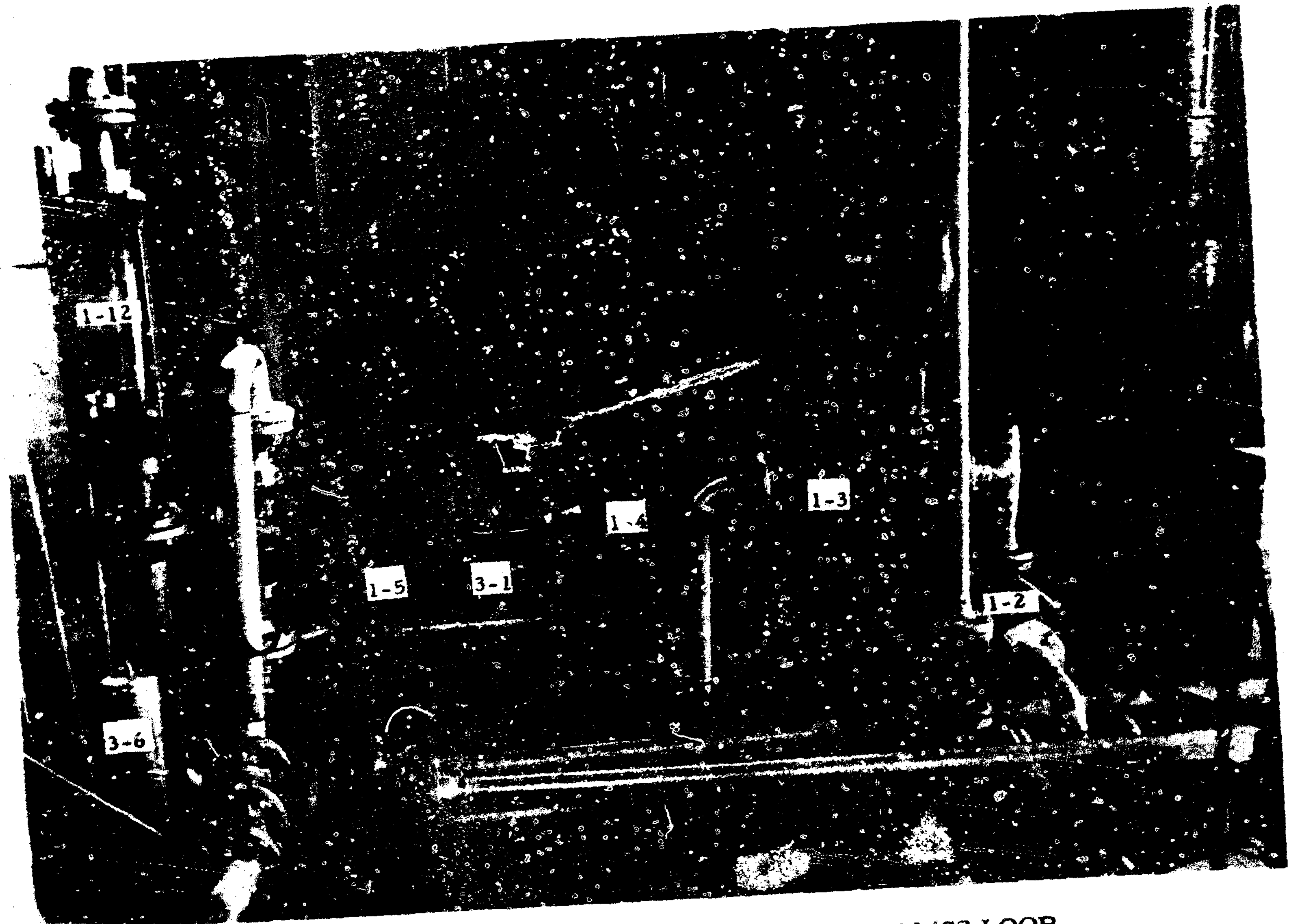

FIGURE 15. PUMP AND HEAT EXCHANGER, Al/SS LOOP

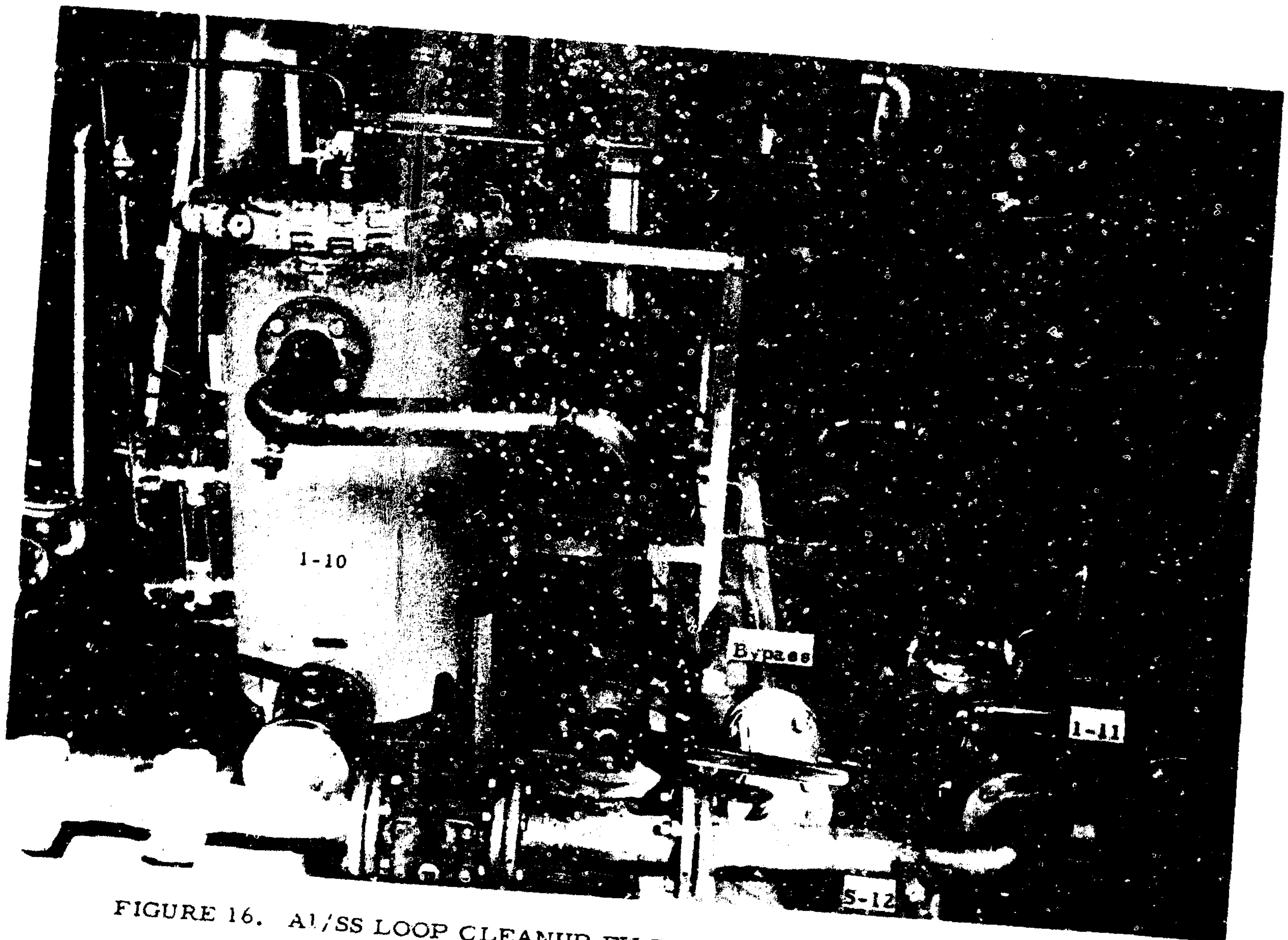

FIGURE 16. Al/SS LOOP CLEANUP FILTER-SEPARATOR AND END VIEW

FIGURE 17. ADDITIVE INJECTION SYSTEM, Al/SS LOOP

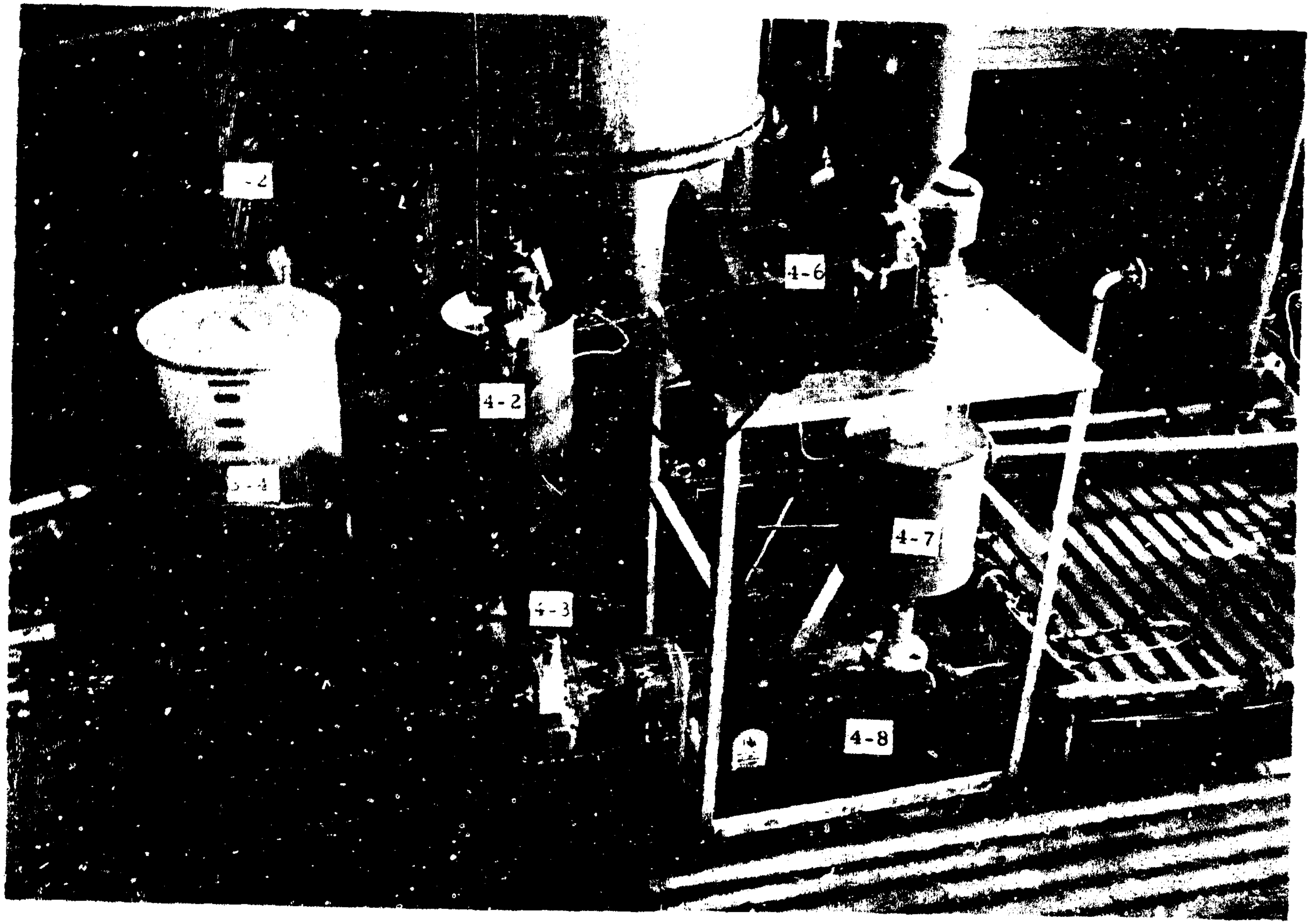

FIGURE 18. SLURRY AND WATER SYSTEMS, Al/SS LOOP

bottom the solid-contaminant injection pump (4-8). To the left of these three components are the slurry mixing tank (4-2) and the slurry mixing pump (4-3). The rotameter (4-1), heat exchanger (4-4), and slurry metering pump (4-5) are hidden from view by intervening components.

Water Injection System

Also visible in Figure 18 are three components of the water injection system: surge tank (3-2), mixing tank (3-4), and injection pump (3-5). The water injection system is shown schematically in Figure 6 (Section II). The other components of this system are obscured in Figure 18, but the water injection system booster pump (3-1) and filter (3-6) are visible in Figure 15.

APPENDIX D

DETAILED PARTS LIST

PARTS LIST FOR Al/SS LOOP
MAIN FUEL LOOP

Identification Number	Quantity	Item
(1-10)	1	Cleanup filter/separator*, Bowser-Briggs, special Model 851-50 (Dwg. No. PFSE 1570) with 6061-T6 aluminum housing with 2-in. ASA flange connections and sight glass, but without automatic controls or water flow chamber.
(1-11)	1	Flow-controller, Cla-Val, Model 40, 2-in. flanged rate-of-flow controller.
	1	Orifice assembly with 2 stainless steel orifice plates, one bored to 0.820 in. for flow rate of 15-45 gpm and one bored to 1.140 in. for flow rate of 30-60 gpm.
(1-3)	1	Pressure reducing valve, Cla-Val, Model 90, 2-in. flanges.
(1-4)	1	Totalizing flowmeter*, Rockwell-Brodie, Model B-40C-AL.
	3	Gage, 4-1/2-in. Helicoid test gage, Type 440 stainless steel, right-hand movement, Acaloy flush case, 0-100 psi, 1/4 NPT back connections, white dial, 1/2 of 1% accuracy.
	3	Gage, 4-1/2-in. Helicoid test gage, Type 440 stainless steel, right-hand movement, Acaloy flush case, 0-150 psi, 1/4 NPT back connections, white dial, 1/2 of 1% accuracy.
	3	Gage, 4-1/2-in. Helicoid test gage, Type 440 stainless steel, right-hand movement, Acaloy flush case, 0-200 psi, 1/4 NPT back connections, white dial, 1/2 of 1% accuracy.
	1	Differential pressure gage, Barton, Model 227. Housing 500-psi aluminum alloy with center block 2024-T4 and heads 360 die-casting alloy, both clear anodized MIL-A-8625 Type I. Viton seal rings. Bellows Type 316 stainless steel. Differential range 0-50 psi. Scale 6-in. diameter, 0-50 uniform graduations.

* This item is described in more detail in Appendix B.

PARTS LIST FOR A1/SS LOOP
MAIN FUEL LOOP

Identification Number	Quantity	Item
(1-5)	1	Heat exchanger*, Young, No. SSF-603-ER-2P with two P/N JM-91 Teflon-impregnated asbestos full-face gaskets installed.
(1-8)	1	Mixing screen assembly, SwRI-fabricated in accordance with SwRI Dwgs. Z-66020 through Z-66025.
(1-2)	1	Centrifugal pump, Gould, Model 3196, size 1-1/2 X 3-10; group M; 1 stage. Case 316 SS, impeller 316 SS, shaft steel, shaft sleeves 316 SS. 25-HP EP motor, 3550 rpm, 3-phase, 60-cycle, 440-volt, Frame 324-U. John Crane Type 9-QPICI 316 (Teflon) mechanical seal. Includes explosion-proof starter with explosion-proof push button. 8-in. impeller installed, 9-5/8-in. impeller extra.
(1-6)	1	Temperature regulator, Hoffman, Series 1110, size 1-1/2-in., temperature range 60-120°F, 10-ft capillary. 1-1/2-in. dia. 304 stainless steel sensing bulb, 30-in. long with 1-1/4NPT stainless steel bushings.
(1-12)	1	Rotameter, Schutte and Koerting, size #9-HCFb 2-in., type 18472, indicating safeguard rotameter with 316 stainless steel end fittings, with nipples and 150-lb ASA raised face stainless steel flanges. Teflon-shielded silicone packing and Teflon gaskets. Size #9-HCFb fluted glass tube, tempered, 250-mm scale length. #93-J stainless steel 316 float. Detachable metal scale (mm) with calibration charts. Connections vertical inlet and outlet per Dwg. 64-S-569M. Maximum flow capacity of light diesel fuel 64.5 to 6.45 gpm. Specific gravity 0.85, viscosity 4.5 cp at 125 psig and 70°F. Accuracy ±2% of maximum flow between 10-100% of scale length. Maximum pressure of 125 psig.
(1-1)	2	Tank, 750-gal, SwRI-fabricated in accordance with SwRI Dwg. D-Z-65006. Tank material 5052-H32 aluminum alloy.

* This item is described in detail in Appendix B.

PARTS LIST FOR Al/SS LOOP
MAIN FUEL LOOP

Identification Number	Quantity	Item
	1	Thermometer, Marsh, rigid-stem direct-mounting piping thermometer for liquid service. To be installed on a 2-in. aluminum pipe perpendicular to the flow. All wetted parts of the thermometer are stainless steel. 1/2 NPT bottom 0-250. Male pipe thread connection. Dial type. 0-100°F standard range.
	1	Thermometer, Marsh, distant-reading, Type 57. 3-1/2-in. dial size. 30-180°F quality movement, 20-ft capillary length. 1/2 NPT standard size "union connected bulb" made of stainless steel (fitting stainless).
	1	Thermometer, Marsh, distant-reading, Type 57. 3-1/2-in. dial size. 0-100°F quality movement, 20-ft capillary length. 1/2 NPT standard size "union connected bulb" made of stainless steel (fitting stainless).
(1-13)	1	Transparent acrylic plastic test housing, SwRI-fabricated in accordance with SwRI Dwgs. 1663-1 to 1663-11, to accept MIL-F-52308 F/S element.
(1-9)	1	Aluminum single-element test housing, to accept MIL-F-52308 F/S element and double-wall canister.
(1-7)	2	Totamitor*, Bowser-Briggs, Model No. 861A-LS-APV 2.5, Dwg. D10040, Spec. No. S10032, working pressure 150 psi.
	1	Valve, 2-in. flanged globe, 150-lb rating, 304 or 316 stainless steel throughout with Teflon or Viton packing and renewable disc.
	7	Valve, ball, McCanna, M502-AL-R-S6, aluminum, 3/8-in. FPT, with reinforced TFE fire seal.

* This item is described in more detail in Appendix B.

PARTS LIST FOR Al/SS LOOP
MAIN FUEL LOOP

Identification Number	Quantity	Item
	6	Valve, ball, McCanna, Type S-151, aluminum, 1-in. flanged ends, with reinforced Teflon seats.
	8	Valve, ball. McCanna, Type S-151, aluminum, 2-in. flanged ends, with reinforced Teflon seats.

PARTS LIST FOR ADDITIVE INJECTION SYSTEM

1. CORROSION INHIBITOR INJECTION SYSTEM

Identification Number	Quantity	Item
(2-2)	1	Metering pump unit, Zenith laboratory unit, Type QF, per Zenith Bulletin W-7310-A and Dwg. 7W-9820-A, with 1/4-HP, 1725 rpm, Master Electric explosion-proof motor, 1-phase, 60-cycle, 115/230-volt; Graham transmission, Model 175G; 26-tooth, 3/4-in. bore Micarta pinion.
	2	Gear pump, Zenith, Type B-4391, size 1/2 (0.297 cc/rev), with Teflon seals, one pump with 36-tooth outer drive gear and other with 44-tooth.
	1	Supporting saddle, Zenith, Type L-4483, right-hand mounting, with 1/8-in. IPS trunnion.
	1	Supporting saddle, Zenith, Type L-4482, left-hand mounting, with 1/8-in. IPS trunnion.
	1	Stand, aluminum, for additive injection system, SwRI fabricated.
(2-1)	1	Tank, Bain-Marie, P/N AP 604, stainless steel, 4-1/4-qt, with stainless steel cover, P/N AP 300-6-1/2C.
	2	Three-way valve, Republic, P/N 321-11TX4D, aluminum alloy, flanged, with Teflon plug.

2. FUEL SYSTEM ICING INHIBITOR INJECTION SYSTEM

Identification Number	Quantity	Item
(2-4)	1	Metering pump unit, Zenith laboratory unit, Type QF, per Zenith Bulletin W-7310-B and Dwg. 7W-9830A, with 1/4-HP, 1725-rpm Master Electric Explosion-proof motor, 1-phase, 60-cycle, 115/230-volt; Graham transmission, Model 175G; 26-tooth Micarta pinion.
	1	Gear pump, Zenith, Type B-4391, size 3 (1.752 cc/rev), with Teflon seals; 42-tooth drive gear.

PARTS LIST FOR
ADDITIVE INJECTION SYSTEM

Identification Number	Quantity	Item
	1	Supporting saddle, Zenith, Type L-4483, right-hand mounting, with 1/4-in. IPS trunnion.
(2-3)	1	Tank, Cole-Palmer Cat. No. 7230, 6-gal, stainless steel, with cover.
	2	Three-way valve, Republic, Lo-Temp valve, P/N 321-11TX6D, aluminum alloy, flanged, with Teflon plug.

PARTS LIST FOR WATER INJECTION SYSTEM

Identification Number	Quantity	Item
(3-6)	1	Filter, Pall Corp., Pall-Guard. Model 30-B, complete with one Type B cartridge.
	1	Filter, replacement cartridge, Type B, for Pall-Guard filter, Model 30-B.
(3-3)	1	Filter assembly, Pall Corp., Model ACS-1001-RZ-16JY (butyl gaskets and seals), complete with one element.
	1	Filter element, Pall Corp., Model ACS-1001-RZ-J (butyl gaskets, Supramesh, stainless steel).
	1	Gage, pressure, 0-60 psi.
	2	Gage, 2 or 2-1/2-in., pressure, 0-150 psi, stainless steel, 1/4 MPT, bottom connection.
	1	Gage, 2 or 2-1/2-in., pressure, 0-50 psi, stainless steel, 1/4 MPT, bottom connection.
(3-5)	1	Pump, Moyno (Robbins and Myers), frame 2L3, Type SSR with 316 SS castings, 316 SS internals, and chromeplated 316 SS rotor turning in natural rubber stator. Pump driven through a Reeves Varidrive, size 111-V1A-18, 5.25/1 ratio, 89-890 rpm, by a 1/2-HP, 440-volt, 60-cycle explosion-proof electric motor.
(3-1)	1	Pump, Worthington, Model 1-TCO-C, standard fitted, turbine type, complete with channel iron base, directly connected through Lovejoy coupling to a 5-HP, 3-phase, 440-volt, 3600-rpm explosion-proof motor (Class I, Group D).
	1	Regulator, back pressure regulating and relief valve, Cashco type 123-6, 3/8-in. FPT, stainless steel body, stainless steel trim, Teflon valve seat, stainless steel diaphragm, max. allowable pressure 400 psig, with hand wheel and locking lever, P/N 830-0117.

PARTS LIST FOR
WATER INJECTION SYSTEM

Identification Number	Quantity	Item
(3-7)	1	Rotameter, Brooks, Model 8-114, hard rubber end fittings, vertical connection, 1/2-in. NPT, tube #R-8M-25-4, float #8-RV-31 (Hastelloy C), neoprene packing, range 0.2 to 2.0 gpm with fluid density of 0.98, viscosity 1.6 cp.
(3-7)	1	Rotameter, Brooks, Model 6-1114, same as previous item except tube #R-6-15-A, Carboloy ball float, 1/4-in. NPT, range 0.02 to 0.2 gpm.
(3-7)	1	Rotameter, Brooks, Model 2-1114, same as previous item except tube #R-2-15-A, Carboloy ball float, 1/4-in. NPT, range 0.0015 to 0.020 gpm.
	1	Switch, pressure, Square D, Nos. 366, 2554, and BJ8G1.
(3-2)	1	Tank, pressure, water booster, galvanized, 120-gal.
(3-4)	1	Tank, American Agile, Series 11000, cylindrical, heavy-duty polyethylene, 55-gal.
	1	Tank cover, American Agile, Series 11003.
	1	Valve, check, 1-1/2-in., water booster line.
	1	Valve, safety, Lunkenheimer, Fig. 658-C.
	1	Valve, ball, 1/4-in. FPT, McCanna 500, stainless steel, with reinforced Teflon fire seal, Fig. M502-S6-R.
	4	Valve, ball, 3/8-in. FPT, McCanna 500, stainless steel, with reinforced Teflon fire seal, Fig. M502-S6-R.
	5	Valve, needle, W. H. Curtin, P/N-22 [illegible] B, Serial PY 271, 316 SS, Teflon seals, 1 [illegible] in. FPT.
	1	Valve, needle, W. H. Curtin, P/N-22 [illegible] D, Serial PY 273, 316 SS, Teflon seals, [illegible]-in. FPT.

PARTS LIST FOR
SOLIDS INJECTION SYSTEM

Identification Number	Quantity	Item
(4-6)	1	Feeder*, Omega, disk type, BIF Industries, Model 22-01, Serial O' 2716.
	1	Gage, pressure, 1/4 MPT, 2 or 2-1/2-in. face, stainless steel, 0-60 psi.
(4-4)	1	Heat exchanger, tube-in-pipe (fabricated on location) for dilute slurry system.
(4-8)	1	Pump, Moyno (Robbins and Myers), frame 3M3, Type SSQ, with SS castings and internals, chrome-plated 316 SS rotor turning 300 to 800 rpm in a Buna N synthetic rubber stator; pump stuffing box equipped with Teflon-impregnated white asbestos packing, pump driven through a flexible coupling, with coupling guard, by means of 2-HP US Vari-drive, 950-190 rpm, 5/1 ratio, 3-phase, 60-cycle, 220/440-volt, explosion-proof motor, with common base for pump and motor.
(4-5)	1	Pump, peristaltic, Sigmanmotor, standard T-8SH series, with Model 10E 400 Zero-Max with lever control, Cat. No. 1701, with 1/6-HP, 110-volt 60-cycle, 1-phase, Class 1, Group D, explosion-proof motor; adjustable from 0.5 to 250 ml/min, with positive locking knob lever control.
(4-3)	1	Pump, Vanton Flex-i-liner, Model CC-S30, complete with stainless steel body-block, Viton A liner, and Class 1, Group D, explosion-proof electric motor, 115-volt, 1-phase.
(4-1)	1	Rotameter, Brooks, Model 10-1110-10, 316 SS end fittings, horizontal connections, 3/4-in. FPT, 303 SS float, Teflon packing, range 1.5 to 9 gpm with fluid density 0.81, viscosity 1.25 cp, 200-psi working pressure.
	1	Stand, for Omega disk feeder.

* This item is described in more detail in Appendix B.

PARTS LIST FOR SOLIDS INJECTION SYSTEM

Identification Number	Quantity	Item
	1	Stirrer, air driven, for slurry mixing tank.
(4-2)	1	Tank, slurry mixing, aluminum, 15-gal, cylindrical with conical bottom, with cover.
(4-7)	1	Tank, swirl hopper, aluminum, 15-gal, cylindrical with conical bottom, with top.
	1	Valve, globe, stainless steel, 3/4-in. FPT, Teflon packing and Teflon seat.
	1	Valve, globe, stainless steel, 3/8-in. FPT, Teflon packing and seat.
	1	Valve, ball, McCanna, M502-AL-R-S6, aluminum, 3/8-in. FPT, with reinforced TFE fire seal.
	2	Valve, ball, McCanna, M502-AL-R-S6, aluminum, 1/2-in. FPT, with reinforced TFE fire seal.
	1	Valve, ball, McCanna, M502-AL-R-S6, aluminum, 3/4-in. FPT, with reinforced TFE fire seal.
	1	Valve, Republic, P/N 321-TX4D, Teflon plug, three-way, flanged, 1/4 tube connections.
	1	Valve, Republic, P/N 321-11TX6D, Teflon plug, three-way, flanged, 3/8 tube connections.
	1	Valve, check, Circle Seal, P/N 830-A-8TT-63, aluminum body, with Viton O-ring, cracking pressure approximately 63-in. water, stainless steel spring, 1/2 tube connections both ends.

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13. ABSTRACT

A 15- to 60-gpm filter-separator test loop has been designed and built for research and development work on jet fuels, additive, and fuel handling equipment. Maximum flexibility has been provided in the loop and in the subsystems for blending and injecting additives, solid contaminants, and water. No materials that are harmful to the newer types of high-quality hydrocarbon fuels have been used in the fuel-wetted components of the loop, and the system consists primarily of aluminum and stainless steel. Initial operations with this loop have been directed toward development of valid single-element test procedures for rating fuel corrosion inhibitors and other additives. The results of the first thirteen tests in this facility have demonstrated its favorable operating characteristics. In these tests, fuel corrosion inhibitors affected principally the plugging rate of filter-separator elements. Considerable scatter was observed in the plugging rates, attributed tentatively to element-to-element variations.

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